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BFISH: A POPULATION DYNAMICS AND FISHERY MANAGEMENT MODEL

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I. INTRODUCTION

The BFISH computer model was initiated to lend insight into the possible effects of alternative fishery management schemes on the time dependent population sizes and geographical distributions of a variety of species of fish, and on some return function associated with those populations. BFISH is a multi-compartment, multi-species simulation model incorporating birth, death, and intercompartmental migration for each species. Several alternative management schemes have been internalized, others may be investigated by manipulation of the time dependent input coefficients. The return function presently incorporated is the fishing yield (in numbers of fish).

Specifically addressed are the attributes of the Hawaiian tuna and billfish fishery, but the model is constructed in a general nature, with the user supplying the compartmental structure and species characteristics. Thus, application to alternative management situations should yield excellent results providing the attributes of the problem are compatible with the assumptions made in the BFISH numerical formulation.

II. NUMERICAL FORMULATION

A. Population Dynamics

The geographical and chronological variations in fish populations are numerically modeled by discretizing the populations in space and time. Geographical compartments are set up by the user, and BFISH calculates the populations in each compartment at discrete, user-specified time intervals. For each species, a single age-class model is utilized that incorporates birth and death in each compartment and migration between compartments.

Numerically, the population dynamics problem is formulated as follows:

$$\frac{dP_{ij}(t)}{dt} = -\left(FC_{ij}(t) + FS_{ij}(t) + XN_j + EM_{ij}(t)\right) P_{ij}(t) + SUM_{ij}(t) + RC_{ij}(t) \tag{1}$$

where

$$FC_{ij}(t) = EC_i(t)*QC_{ij}(t)$$

$$FS_{ij}(t) = ES_i(t)*QS_{ij}(t)$$

$$EM_{ij}(t) = \sum_{k \neq i} XM_{i \to k,\, j}(t)$$

$$SUM_{ij}(t) = \sum_{k \neq i} XM_{k \to i,\, j}(t)*P_{kj}(t)$$

$$RC_{ij}(t) = \text{minimum} \begin{cases} FR_{ij}(t)*RP_j(t - m_j)* \sum_k P_{kj}(t - m_j) \\ FR_{ij}(t)*RCMAX_j \end{cases}$$

and

$EC_i(t)$ = commercial fishing effort in compartment i at time t.

$ES_i(t)$ = sport fishing effort in compartment i at time t.

$FC_{ij}(t)$ = commercial fishing mortality coefficient for species j in compartment i at time t.

$FS_{ij}(t)$ = sport fishing mortality coefficient for species j in compartment i at time t.

$P_{ij}(t)$ = population of species j in compartment i at time t.

$QC_{ij}(t)$ = commercial fishing catchability coefficient for species j in compartment i at time t.

$QS_{ij}(t)$ = sport fishing catchability coefficient for species j in compartment i at time t.

$RC_{ij}(t)$ = recruitment rate to species j in compartment i at time t.

$RCMAX_j$ = maximum recruitment rate for species j.

$RP_j(t)$ = reproduction coefficient for species j at time t.

$XM_{i \to k, j}(t)$ = migration coefficient for species j migrating from compartment i to compartment k at time t.

XN_j = natural mortality coefficient for species j.

$FR_{ij}(t)$ = fraction of new recruits to species j at time t that will be recruited to compartment i.

m_j = maturation age (age when fish enter the fishery) for species j.

The BFISH model incorporates the concept of a time cycle equal to some integral number of discrete time intervals, or timesteps. The user specifies the length of each timestep and the number of timesteps in each cycle. The input time dependent coefficients are

then characterized by the user for the first cycle, and BFISH repeats the values each succeeding cycle. An obvious time structure would be to use annual cycles with weekly, monthly, or quarterly timesteps depending on the availability of data and desired output resolution. By characterizing the necessary coefficients over a single cycle, calculations may proceed over any number of desired cycles without additional user involvement. The option exists, of course, to set up a single-cycle simulation, with the cycle being arbitrarily long. This would require, however, characterization of the time dependent coefficients over the entire span of the simulation, which could be very tiresome. The cycle concept takes advantage of the cyclical nature of such activities as spawning and migration to economize on input labors without reducing the model's capabilities.

Note that the recruitment rate to a given species at any time t is a function of the total population of that species at some prior time (= the maturation age of that species). That is, no geographical effect on spawning activity is accounted for, as the distribution of the fish at time of spawning ($t = t_s$) does not affect the total number of recruits at time $t = t_s + m_j$. Presently, the new recruits to species j are distributed to the various compartments based upon the fraction of the total population of species j that resides in each compartment at the beginning of the timestep being calculated, i.e.,

$$FR_{ij}(t) = \frac{P_{ij}(t_o)}{\sum_i P_{ij}(t_o)} \quad (t_o \leq t \leq t_1) \qquad (2)$$

t_o = time at beginning of present timestep.

t_1 = time at end of present timestep.

No species interactions are modeled, hence the equations for each species may be solved independently. In the following discussion the subscript j is dropped for clarity, with the understanding that the equations apply to and are solved for each species in turn. The intercompartmental migration coefficients are coupling agents between the population equations for each compartment. Thus, equation (1) describes a system of N (N = number of compartments) coupled differential equations for each species:

$$\frac{d\bar{P}}{dt} = A\bar{P} + \bar{K} \tag{3}$$

where

$\bar{P}$ = a column vector of compartment populations, i.e.,

$$\bar{P} = \begin{bmatrix} P_1(t) \\ P_2(t) \\ \vdots \\ P_N(t) \end{bmatrix}$$

A = (N x N) matrix with the migration coefficients in the off-diagonal elements.

$$A = \left[a_{ik}\right]$$

where

$$a_{ii} = -\left(FC_i(t) + FS_i(t) + XN + EM_i(t)\right)$$

$$a_{ik} = XM_{k \to i}(t)$$

and $\bar{K}$ is a column vector of recruitment rates to each compartment, i.e.,

$$k_i = \text{minimum}\begin{cases} FR_i(t)*RP(t-m)*\sum_{\ell=1}^{N} P_\ell(t-m) \\ FR_i(t)*RCMAX \end{cases}$$

B. Yield Equations

The commercial and sport fishing yields of species j in compartment i during the time interval from t_o to t_1 can be expressed:

$$YIELDC_{ij}(t_o, t_1) = \int_{t_o}^{t_1} EC_i(t)*QC_{ij}(t)*P_{ij}(t)dt \qquad (4)$$

$$YIELDS_{ij}(t_o, t_1) = \int_{t_o}^{t_1} ES_i(t)*QS_{ij}(t)*P_{ij}(t)dt \qquad (5)$$

where

$YIELDC_{ij}(t_o, t_1)$ = commercial fishing yield of species j in compartment i over the time interval from t_o to t_1.

$YIELDS_{ij}(t_o, t_1)$ = sport fishing yield of species j in compartment i over the time interval from t_o to t_1.

III. NUMERICAL SOLUTION

A. Population Dynamics

The population dynamics problem equation (3) is solved using a fourth order Runge-Kutta numerical integration scheme. If we denote the right-hand side of equation (3) by $f(\bar{P}, t)$, we have for compartment i:

$$\frac{dP_i}{dt} = f\left(P_1(t), P_2(t), \ldots P_N(t), t\right) \tag{6}$$

where the species subscript j is dropped for clarity. The computing procedure for the fourth order Runge-Kutta integration of equation (6) involves the use of four auxiliary quantities $XK1_i$, $XK2_i$, $XK3_i$, and $XK4_i$. If we know $P_i(t_o)$, we calculate $P_i(t_1)$ from

$$P_i(t_i) = P_i(t_o) + \frac{1}{6}\left(XK1_i + 2*XK2_i + 2*XK3_i + XK4_i\right) \tag{7}$$

where

$$XK1_i = H*f\left(P_1(t_o), P_2(t_o), \ldots P_N(t_o), t_o\right)$$

$$XK2_i = H*f\left(P_1(t_o) + \frac{XK1_1}{2}, \ldots P_N(t_o) + \frac{XK1_N}{2}, t_o + \frac{H}{2}\right)$$

$$XK3_i = H*f\left(P_1(t_o) + \frac{XK2_1}{2}, \ldots P_N(t_o) + \frac{XK2_N}{2}, t_o + \frac{H}{2}\right)$$

$$XK4_i = H*f\left(P_1(t_o) + XK3_1, \ldots P_N(t_o) + XK3_N, t_o + H\right)$$

$$H = t_1 - t_o$$

The stability and accuracy of this method are dependent upon the timestep size H. In general, the timestep size should be sufficiently small so that the higher order terms (order > 4) neglected in the solution scheme are negligible. In practice, it is very difficult to know a priori what timestep size to assign a given BFISH analysis. Indeed, at times the timestep size will not be arbitrary, but will have a lower bound imposed by available data. For these reasons, it was considered appropriate to monitor the calculations as they proceed. This is done by calculating and printing out the Collatz coefficient of "sensitiveness":[1]

$$S_i = \frac{XK2_i - XK3_i}{XK1_i - XK2_i} \tag{8}$$

A reasonable timestep size will yield a value of S close to unity. If S is too much larger than unity, a smaller timestep size is desirable. If S is too much smaller than unity, a larger timestep size may allow the user to decrease computational costs while maintaining desired accuracy. Validation runs with the BFISH model yield excellent agreement with exact analytical results for $S \leq 0.5$, and this value is suggested as a rule of thumb. However, S values of twice that size can be tolerated with only minimal loss of accuracy ($\sim$5%).

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[1]Collatz, Lothar. 1966. The numerical treatment of differential equations. Springer-Verlag, New York, Inc., N.Y., 568 p.

B. Yield Equations

The numerical technique used to calculate the fishing yields is presented here in terms of a general yield function. Specific application to commercial and sport fishing yields in the BFISH model merely requires the appropriate effort and catchability coefficient functions.

The general yield function, Y, for a given species and compartment, is defined by:

$$Y(t) = E(t)*Q(t)*P(t) \tag{9}$$

E(t) = fishing effort

Q(t) = fishing catchability coefficient

P(t) = fish population

The fishing yield over some time interval (t_o, t_1) will be the integral of equation (9) over the interval:

$$YIELD = \int_{t_o}^{t_1} Y(t)dt = \int_{t_o}^{t_1} E(t)*Q(t)*P(t)dt \tag{10}$$

If we assume that Y(t) on the interval can be represented by a third order Taylor series expansion about t_o, we have

$$Y(t) = Y(t_o) + Y'(t_o)\Delta t + Y''(t_o)\frac{\Delta t^2}{2} + Y'''(t_o)\frac{\Delta t^3}{6} \tag{11}$$

for $(t_o \leq t \leq t_1)$

$\Delta t = t - t_o$

which is easily analytically integrated to give:

$$\int_{t_o}^{t_1} Y(t)dt = Y(t_o)H + Y'(t_o)\frac{H^2}{2} + Y''(t_o)\frac{H^3}{6} + Y'''(t_o)\frac{H^4}{24} \qquad (12)$$

where $H = t_1 - t_o$.

Thus, if equation (11) is an adequate representation of the yield function $Y(t)$ on (t_o, t_1), and if we can characterize the expansion coefficients, the fishing yield over the interval can be easily calculated from equation (12).

Note that $E(t)$ and $Q(t)$ are input functions of time, and their values and derivatives are known for all time t. At the beginning of a timestep the population $P(t_o)$ is known, and by substitution into equation (3) $P'(t_o)$ is known. Similarly, at the completion of the Runge-Kutta calculations over the timestep $P(t_1)$ and $P'(t_1)$ will be known. Hence, we can easily calculate

$$Y(t_o) = E(t_o)*Q(t_o)*P(t_o) \qquad (13)$$

$$Y'(t_o) = E(t_o)*Q(t_o)*P'(t_o) + E(t_o)*Q'(t_o)*P(t_o) + E'(t_o)*Q(t_o)*P(t_o) \qquad (14)$$

$$Y(t_1) = E(t_1)*Q(t_1)*P(t_1) \qquad (15)$$

$$Y'(t_1) = E(t_1)*Q(t_1)*P'(t_1) + E(t_1)*Q'(t_1)*P(t_1) + E'(t_1)*Q(t_1)*P(t_1) \qquad (16)$$

By evaluating equation (11) and its first time derivative at the end of the timestep ($t = t_1$) we get

$$Y(t_1) = Y(t_o) + Y'(t_o)H + Y''(t_o)\frac{H^2}{2} + Y'''(t_o)\frac{H^3}{6} \qquad (17)$$

$$Y'(t_1) = Y'(t_o) + Y''(t_o)H + Y'''(t_o)\frac{H^2}{2}$$

Since we know $Y(t_o)$, $Y'(t_o)$, $Y(t_1)$, and $Y'(t_1)$, equations (17) form a system of two equations in two unknowns $\left(Y''(t_o) \text{ and } Y'''(t_o)\right)$. This system is solved to yield the recursion equations:

$$Y'''(t_o) = -\frac{12}{H^3}\left(Y(t_1) - Y(t_o)\right) + \frac{6}{H^2}\left(Y'(t_1) + Y'(t_o)\right) \qquad (18)$$

$$Y''(t_o) = \frac{2}{H^2}\left(Y(t_1) - Y(t_o)\right) - \frac{H}{3}Y'''(t_o) - \frac{2}{H}Y'(t_o) \qquad (19)$$

We can now complete the expansion equation (11) and calculate the integral equation (12).

This technique is generally applicable to any function on any interval (t_o, t_1) for which the appropriate boundary values and derivatives are known. Specifically, in BFISH, it is used in three different calculations. The first two are the yield function for commercial and sport fishing yields, respectively.

$$\text{YIELDC} = \int_{t_o}^{t_1} EC(t)*QC(t)*P(t)dt \qquad (20)$$

YIELDC = commercial fishing yield

$$\text{YIELDS} = \int_{t_o}^{t_i} ES(t)*QS(t)*P(t)dt \tag{21}$$

YIELDS = sport fishing yield

These yields are calculated for each species and compartment over each timestep. The third application of the technique is in the recruitment calculation, which is discussed in the next section.

The basic assumption implicit in this technique is that the function to be integrated can be adequately described on the interval of interest by a third order Taylor series. Validation runs with BFISH are in excellent agreement with exact analytical results for timestep sizes which yield a Collatz coefficient $S \leq 0.5$. Thus, a high degree of accuracy can be maintained in both the Runge-Kutta and yield calculations by keeping S within the recommended range.

C. Recruitment

As was noted previously, the recruitment rate at time t is dependent upon the spawning population at some previous time (t - m). Specifically, the recruitment rate for a given species at time t is given by

$$\left.\frac{dP(t)}{dt}\right|_{\text{RECRUITMENT}} = \text{minimum}\begin{cases} RP(t-m)*P_{TOT}(t-m) \\ RCMAX \end{cases} \tag{22}$$

RP = reproduction coefficient

P_{TOT} = total population

RCMAX = maximum recruitment rate

Here our recruitment rate as a function of population size is divided into a proportional region and a constant region. If we define a reproduction function

$$RPP(t) = \text{minimum}\begin{cases} RP(t)*P_{TOT}(t) \\ RCMAX \end{cases} \tag{23}$$

we can express the total number of fish recruited to a population over an interval (t_o, t_1) as

$$\Delta P = \int_{t_o}^{t_1} dP = \int_{t_o}^{t_1} RPP(t - m)dt \tag{24}$$

The BFISH model incorporates the concept of a recruitment period for each species. This is some arbitary segment of each time cycle during which the fish are assumed to spawn. The maturation age, m, is input as the number of cycles between the time of spawning and the time when the new fish enter the fishery. Thus, spawning activity during the k^{th} timestep of cycle L will produce new recruits to the population during the k^{th} timestep of cycle L + m. The recruitment period itself is an arbitrary number of timesteps in length, and occurs at the same time each cycle. Numerically, the problem is to characterize the reproduction function, RPP, over the recruitment period for each cycle, and store the characterization for retrieval m cycles later.

Using the same arguments as applied to the yield function, we know RPP and RPP′ at the beginning and end of each timestep, and thus can calculate the integral of the function over the timestep in the same manner using a third order Taylor series. This integral, equation (24), is evaluated for each timestep in the recruitment period. The total number of fish that will be added to the population by the recruitment mechanism m cycles later is

$$\bar{R} = \sum_{i=1}^{N_R} \Delta P = \sum_{i=1}^{N_R} \int_{t_{oi}}^{t_{1i}} RPP(t)dt \qquad (25)$$

N_R = number of timesteps in the recruitment period.

t_{oi} = time at beginning of timestep i in the recruitment period.

t_{1i} = time at end of timestep i in the recruitment period.

If we define:

condition 1 $\equiv RP(t)*P_{TOT}(t) < RCMAX$

condition 2 $\equiv RP(t)*P_{TOT}(t) \geq RCMAX$

we can see that at the end of each recruiment period, BFISH will have calculated:

$$RPP(t_I) = \begin{cases} RP(t_I)*P_{TOT}(t_I) & ; \text{ condition 1} \\ RCMAX & ; \text{ condition 2} \end{cases} \qquad (26)$$

$$RPP'(t_I) = \begin{cases} RP(t_I)*P'_{TOT}(t_I) + RP'(t_I)*P_{TOT}(t_I) & ; \text{ condition 1} \\ 0 & ; \text{ condition 2} \end{cases} \tag{27}$$

$$RPP(t_F) = \begin{cases} RP(t_F)*P_{TOT}(t_F) & ; \text{ condition 1} \\ RCMAX & ; \text{ condition 2} \end{cases} \tag{28}$$

$$RPP'(t_F) = \begin{cases} RP(t_F)*P'_{TOT}(t_F) + RP'(t_F)*P_{TOT}(t_F) & ; \text{ condition 1} \\ 0 & ; \text{ condition 2} \end{cases} \tag{29}$$

$$\bar{R} = \int_{t_I}^{t_F} RPP(t)dt = \sum_{i=1}^{N_R} \int_{t_{oi}}^{t_{1i}} RPP(t)dt \tag{30}$$

where t_I = time at the beginning of the recruitment period.

t_F = time at the end of the recruitment period.

Next, we assume that the function RPP(t) can be represented over the entire recruiment period (t_I, t_F) by a fourth order Taylor series expansion about t_I:

$$RPP(t) = RPP(t_I) + RPP'(t_I)\Delta t + RPP''(t_I)\frac{\Delta t^2}{2} + RPP'''(t_I)\frac{\Delta t^3}{6} + RPP''''(t_I)\frac{\Delta t^4}{24} \quad (t_I \leq t \leq t_F) \tag{31}$$

$$\Delta t = t - t_I$$

Differentiating equation (31) with respect to time yields

$$RPP'(t) = RPP'(t_I) + RPP''(t_I)\Delta t + RPP'''(t_I)\frac{\Delta t^2}{2} + RPP''''(t_I)\frac{\Delta t^3}{6} \tag{32}$$

and integrating equation (31) over the recruitment period yields:

$$\bar{R} = RPP(t_I)\Delta t_R + RPP'(t_I)\frac{\Delta t_R^2}{2} + RPP''(t_I)\frac{\Delta t_R^3}{6} + RPP'''(t_I)\frac{\Delta t_R^4}{24} + RPP''''(t_I)\frac{\Delta t_R^5}{120} \tag{33}$$

where $\Delta t_R = t_F - t_I$

Note that we know $RPP(t_I)$, $RPP'(t_I)$, $RPP(t_F)$, $RPP'(t_F)$, and $\bar{R}$. Thus, by evaluating equations (31) and (32) at $t = t_F$, and augmenting the two resulting equations with equation (33), we have a system of 3 equations in 3 unknowns $\left(RPP''(t_I),\ RPP'''(t_I),\ \text{and } RPP''''(t_I)\right)$. This system can be solved to yield the recursion equations:

$$RPP''''(t_I) = \frac{720}{\Delta t_R^5}\bar{R} - \frac{360}{\Delta t_R^4}\left(RPP(t_F) + RPP(t_I)\right) + \frac{60}{\Delta t_R^3}\left(RPP'(t_F) - RPP'(t_I)\right) \tag{34}$$

$$RPP'''(t_I) = \frac{6}{\Delta t_R^{\,2}}\left(RPP'(t_F) + RPP'(t_I)\right) = -\frac{12}{\Delta t_R^{\,3}}\left(RPP(t_F) - RPP(t_I)\right) - \frac{\Delta t_R}{2} RPP''''(t_I) \tag{35}$$

$$RPP''(t_I) = \frac{2}{\Delta t_R^{\,2}}\left(RPP(t_F) - RPP(t_I)\right) - \frac{2}{\Delta t_R} RPP'(t_I) - \frac{\Delta t_R}{3} RPP'''(t_I) - \frac{\Delta t_R^{\,2}}{12} RPP''''(t_I) \tag{36}$$

This completes the characterization of the Taylor series expansion of the reproduction function RPP(t) over the recruitment period. The coefficients of the expansion are stored, and m cycles in the future, recalled. The recruitment rate at time t for a given cycle is then:

$$RC(t) = RPP(t - m) \qquad t_I + m \leq t \leq t_F + m \tag{37}$$

$$RC(t) = 0 \qquad t < t_I + m \tag{38}$$

$$t > t_F + m$$

The total recruitment rate for a given species is then divided among the compartments based upon the fraction of the total species population that resides in each at the beginning of the timestep.

Thus, after the first m cycles the recruitment mechanism will be fully self-contained. Some provision must be made, however, to recruit fish to the population from time = 0. To accomplish this, the user specifies a constant recruitment rate, RCINIT, that is used during the recruitment periods of cycles 1 through m. After the m^{th} cycle, this initial recruitment rate is superseded by the BFISH calculated recruitment rate.

D. Internal Management Schemes

The BFISH model has the capability of keeping separate population and yield totals for a user-specified management area, which is a subset of the total number of compartments used in the model. Commercial fishing effort for each compartment may be supplied by the user or calculated by BFISH. Within the management area, additional constraints may be placed upon the commercial fishing effort in the form of effort or yield ceilings. Some inter-species numerical coupling may exist as a result of the commercial fishing fleet keying on more than one species, or multi-species yield ceilings being specified by the user. As described below, when this coupling exists it is manifested during step changes in the applied effort function across timestep boundaries, and does not affect the solution procedure described earlier.

The options available to the user for the distribution of commercial fishing effort and the management of the managed area are described below:

1) MANAGEMENT OPTION 1

When the first management option is specified, the commercial fishing effort function must be supplied by the user for each compartment separately. A management area may be specified (some arbitrary subset of the total compartment set), for which population and yield subtotals will be kept, but no special calculations or constraints will be applied.

2) MANAGEMENT OPTION 2

When the second management option is specified, BFISH will internally calculate the commercial fishing effort in each compartment subject to an effort ceiling placed on each managed compartment. The user must supply the total commercial fishing effort function (total effort = effort summed over all compartments) and the effort ceiling function for each managed compartment.

The total commercial fishing effort function is utilized as a step function with the total effort assumed constant over each timestep. Hence, if we define

TE(t) = total commercial fishing effort function supplied by the user

BFISH will calculate the total fishing effort to be divided up among the various compartments from:

$$\begin{aligned} &\text{TEFORT} = TE(t_1) && t_1 < t \leq t_2 \\ &\text{TEFORT} = TE(t_2) && t_2 < t \leq t_3 \\ &\quad \vdots && \quad \vdots \\ &\text{TEFORT} = TE(t_k) && t_k < t \leq t_{k+1} \end{aligned} \tag{39}$$

where

TEFORT = total commercial fishing effort used by BFISH

t_k = time at beginning of k^{th} timestep.

Thus, the total commercial fishing effort function supplied by the user differs from the other time dependent input functions in that it is never evaluated between timestep boundaries.

It is assumed that the commercial fishing fleet will key on the movements of their target species, and thus the most commercial effort will be found where there are the most fish. It is recognized, however, that the fleet may not instantaneously recognize fish movement, and a lag time may exist between the real fish distribution and the response of the commercial fleet. Consequently, a lag time option is included in the BFISH model, invoked by assigning a value of 0 or 1 to the interger variable ILAG. If ILAG = 0, the commercial fishing effort in each compartment for each timestep is calculated based on the total effort available for that timestep and the fraction of the total target population that resides in each compartment at the beginning of the timestep. If ILAG = 1, the commercial effort is distributed based on the target population distribution at the beginning of the previous timestep, i.e.,

$$\text{If ILAG} = 0;\ E_i(t) = \frac{PTARGT_i(t_k)}{TTARGT(t_k)} * TE(t_k) \qquad t_k < t \leq t_{k+1}$$

$$\text{If ILAG} = 1;\ E_i(t) = \frac{PTARGT_i(t_{k-1})}{TTARGT(t_{k-1})} * TE(t_k) \qquad t_k < t \leq t_{k+1} \tag{40}$$

$E_i(t)$ = commercial fishing effort applied to compartment i at time t

t_k = time at beginning of timestep k

$PTARGT_i(t)$ = target population in compartment i at time t

$TTARGT(t) = \sum_i PTARGT_i(t)$

Note that $E_i(t)$ is constant over each timestep with step changes at the timestep boundaries. The target population may be composed of one or several constituent species. Thus, the movement of the commercial fishing fleet may be modeled as a function of the movement of the target species of fish. If this is all that is required, the user would specify a null set of managed compartments. If, however, a management area is used, then the compartments within the managed area are subject to the additional constraint of user-supplied effort ceilings.

$$CEILNG_i(t) = CL_i(t_k) \quad t_k < t \leq t_{k+1} \tag{41}$$

$CL_i(t)$ = ceiling function for compartment i evaluated at time t

$CEILNG_i(t)$ = effort ceiling used by BFISH for compartment i at time t

Note that the effort ceiling function, like the total effort function, is used as a step function constant across each timestep. The commercial fishing effort calculation will then proceed as follows:

a) Calculate the commercial fishing effort in each compartment from equation (40).

b) Check each managed compartment to see if the calculated fishing effort exceeds the effort ceiling for that compartment.

c) If the calculated effort exceeds the ceiling, set the effort equal to the ceiling and save the amount of excess effort that must be distributed elsewhere. Remove the compartment from further calculations.

d) After (b) and (c) have been completed for all compartments, distribute the accumulated excess effort among the compartments still in the calculation based on their respective target populations.

e) Go back to (b).

This iterative process continues until there is no more excess effort at the end of step (c).

3) MANAGEMENT OPTION 3

When the third management option is specified, BFISH will again internally calculate the distribution of the total commercial fishing effort from equation (40), except that a yield ceiling is placed on each compartment in the management area. This yield ceiling is not time dependent, and is used as a cycle-to-date yield limit. Thus, compartment i is removed from the calculations if

$$YMANAG_i(t_k) \geq YCEILNG_i$$

$YMANAG_i(t)$ = total commercial fishing yield of managed species taken during the present time cycle in compartment i up to time t.

t_k = time at the beginning of the k^{th} timestep.

$YCEILNG_i$ = cycle-to-date yield ceiling for compartment i

The managed species may be all the species modeled or some subset thereof. Note that the cycle-to-date yield is checked and the effort is distributed at the beginning of each timestep. It is therefore possible for the commercial fishing yield in a managed compartment to be less than the applied ceiling at the beginning of the timestep, and exceed the ceiling during the timestep. This will be flagged at the beginning of the next timestep, and no more commercial fishing effort will be applied to that compartment for the remainder of the time cycle. Naturally, all cycle-to-date totals are reset to zero at the beginning of each time cycle.

For the third management option, the user must supply the total commercial fishing effort function, the constituent compartments in the management area, the yield ceiling for each managed compartment, the constituent species in the target fish population, and the constituent species in the managed fish population, and the ILAG value.

IV. INPUTS

A. General Information

The majority of the inputs required to run a BFISH analysis are characterizations of the time dependent coefficients. As mentioned earlier, these functions need only be characterized over the first time cycle, and are repeated for each subsequent cycle. Thus, one must completely describe each time dependent input function over the interval from (time = zero) to (time = end-of-cycle). Using f as a general function for demonstration purposes, we must describe

$$f(t) \qquad 0 \leq t \leq t_F$$

where t_F = time at end-of-cycle

There are two alternative ways to describe f(t) over the cycle available to the BFISH user. First, if f(t) is smooth and well-behaved, it might be possible to represent f as a polynomial in time:

$$f(t) = a_1 + a_2 t + a_3 t^2 + \ldots a_{n+1} t^n \tag{42}$$

$$= \sum_{i=o}^{n} a_{i+1} t^i$$

$$(0 \leq t \leq t_F)$$

In this case the user need only specify n, the order of the polynomial, and the (n + 1) coefficients a_i.

The second type of representation is to specify explicitly what value f(t) is to take at the timestep boundaries. BFISH will then treat f(t) as a piecewise linear function with as many "pieces" as there are timesteps. The value of f(t) at any time during the timestep will fall along the line connecting the user supplied values at the timestep boundaries. For example, f(t) would be evaluated on (t_k, t_{k+1}) from

$$f(t) = f(t_k) + \left[\frac{t - t_k}{t_{k+1} - t_k}\right] * \left[f(t_{k+1} - f(t_k)\right] \quad (t_k \leq t \leq t_{k+1}) \qquad (43)$$

where

$f(t_k)$ = user supplied value of f(t) at the beginning of the k^{th} timestep

t_k = time at the beginning of the k^{th} timestep.

The end-of-timestep value for any timestep is the same as the beginning-of-timestep value for the next timestep. Thus, by supplying the beginning of timestep values for each timestep in the cycle, a continuous piecewise linear function is completely described across the cycle.

It is also realized that many parameter estimation procedures are not well suited for calculating time-dependent variables, and estimating some of the coefficients may only be tractable if one assumes they remain constant over a timestep. Thus, the user has the option of making the migration coefficients, commercial fishing catchability coefficients, or sport fishing catchability coefficients piecewise constant. Using this option,

the function is represented in either of the two manners described above, but is evaluated at the beginning of each timestep and held constant over the timestep. This option is invoked by assigning a value of 2 to the integer variables IMIG, IQC, and IQS for the migration coefficients, commercial fishing catchability coefficients, and sport fishing catchability coefficients, respectively. By assigning a value of 1 to the above integer variables, the user has elected to represent the corresponding coefficient as a continuous function.

When describing an input function, the input card is, in general, utilized as follows:

COLS 1 - 3 : species number

COLS 4 - 6 : compartment number

COLS 7 - 9 : type of representation

(1 = polynomial)

(2 = explicit)

COLS 10 - 12 : order of the polynomial (if type 1) or card number (if type 2)

COLS 13 - 23, 24 - 34, 35 - 45, 46 - 56, 57 - 67, 68 - 78 : fixed decimal input values for polynomial coefficients (if type 1) or modal values (if type = 2).

Thus, columns 1-12 hold four integer variables of field width 3, and columns 13-78 hold six fixed decimal variables of field width 11. This breakdown is reflected in the standard BFISH coding form shown in Figure 1.

As an example of a polynomial input, assume we wish to represent f(t) as a fourth order polynomial:

$$f(t) = 5. + 0.06\ t - 0.7\ t^3 + 0.0006\ t^4 \qquad (44)$$

$$(0 \leq t \leq t_F)$$

where f(t) describes some time dependent coefficient for species 1 and compartment 3. In general, the species will be specified once and need not be repeated for all inputs pertaining to that species. Assume this has been done on some previous card. The necessary input card representing f(t) would then appear as in Figure 2A. Note that the compartment number, type of representation, order of the polynomial, and the polynomial coefficients all appear on the same input card. This format is characteristic of polynomial (type 1) variables. Since there is space on each card for 6 fixed decimal coefficients, the user is limited to polynomials of order 5 or less. The effort ceiling polynomial, as noted below, is restricted to order 4 or less.

Figure 1.-- BFISH coding form.

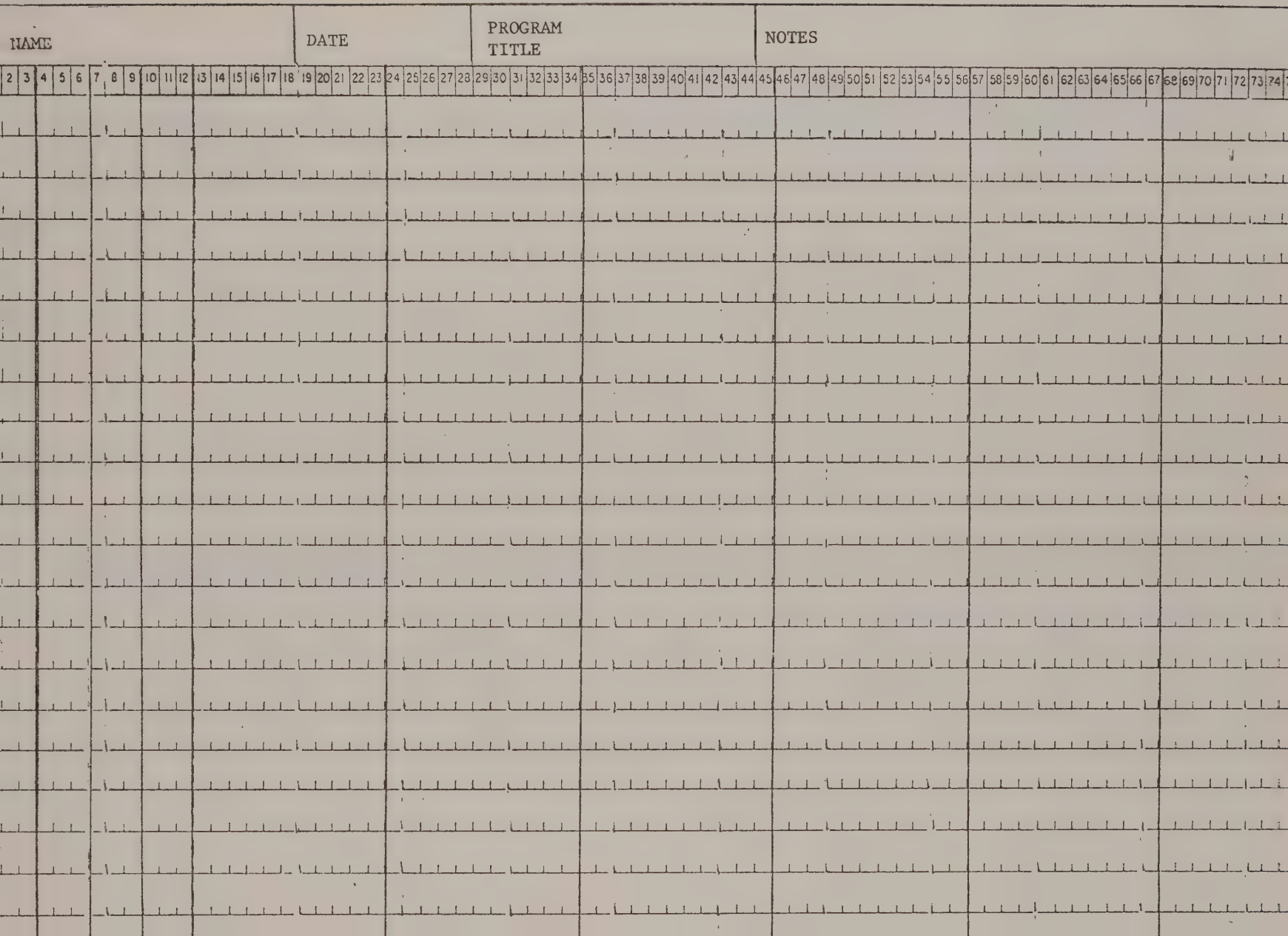


Figure 2A.--Type 1 representation.

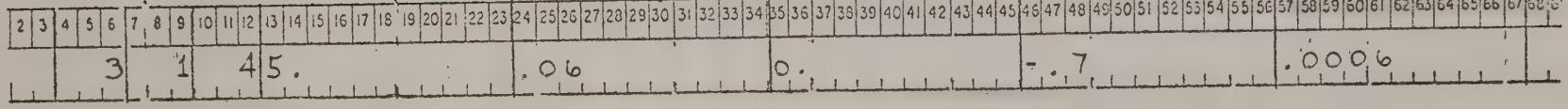
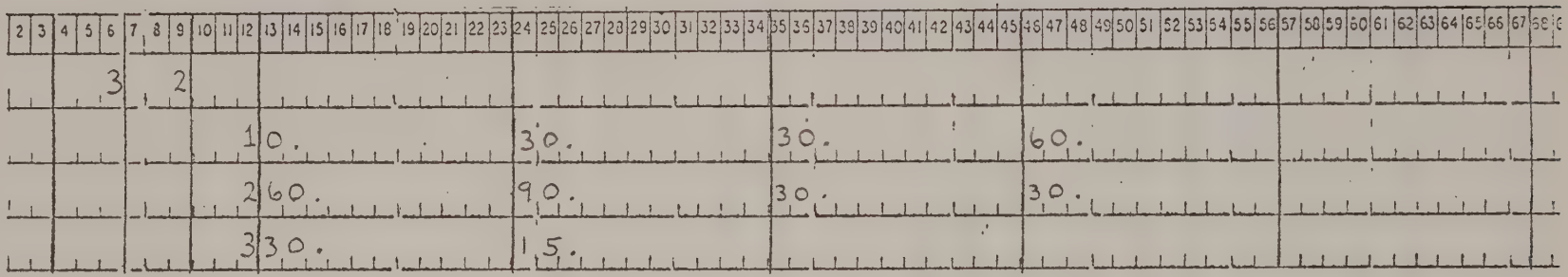


Figure 2B.--Type 2 representation.



Now suppose the user has decided to break up each cycle into 10 timesteps, and wishes to represent f(t) over each cycle as shown in Figure 3. In this case f would be explicitly represented (type 2) and the necessary input cards would be as shown in Figure 2B. Note that the set of cards with the input nodal values follows the card describing the compartment number and type of representation, each card containing nodal points is numbered, and a maximum of four nodal values appears on each card. These characteristics will always be true for explicit (type 2) variables. The number of timesteps per cycle, and hence the number of cards necessary to list all the nodal values, is arbitrary, but a nodal value must appear for each timestep.

If f(t) were a function describing a migration coefficient, commercial fishing catchability coefficient, or sport fishing catchability coefficient, the user could invoke the piecewise constant option by setting IMIG, IQC, or IQS = 2. In this case, f(t) would be evaluated at the beginning of each timestep and held constant at that value throughout the timestep, i.e.,

$$f(t) = f(t_k) \quad t_k < t \leq t_{k+1}$$

t_k = time at beginning of timestep k

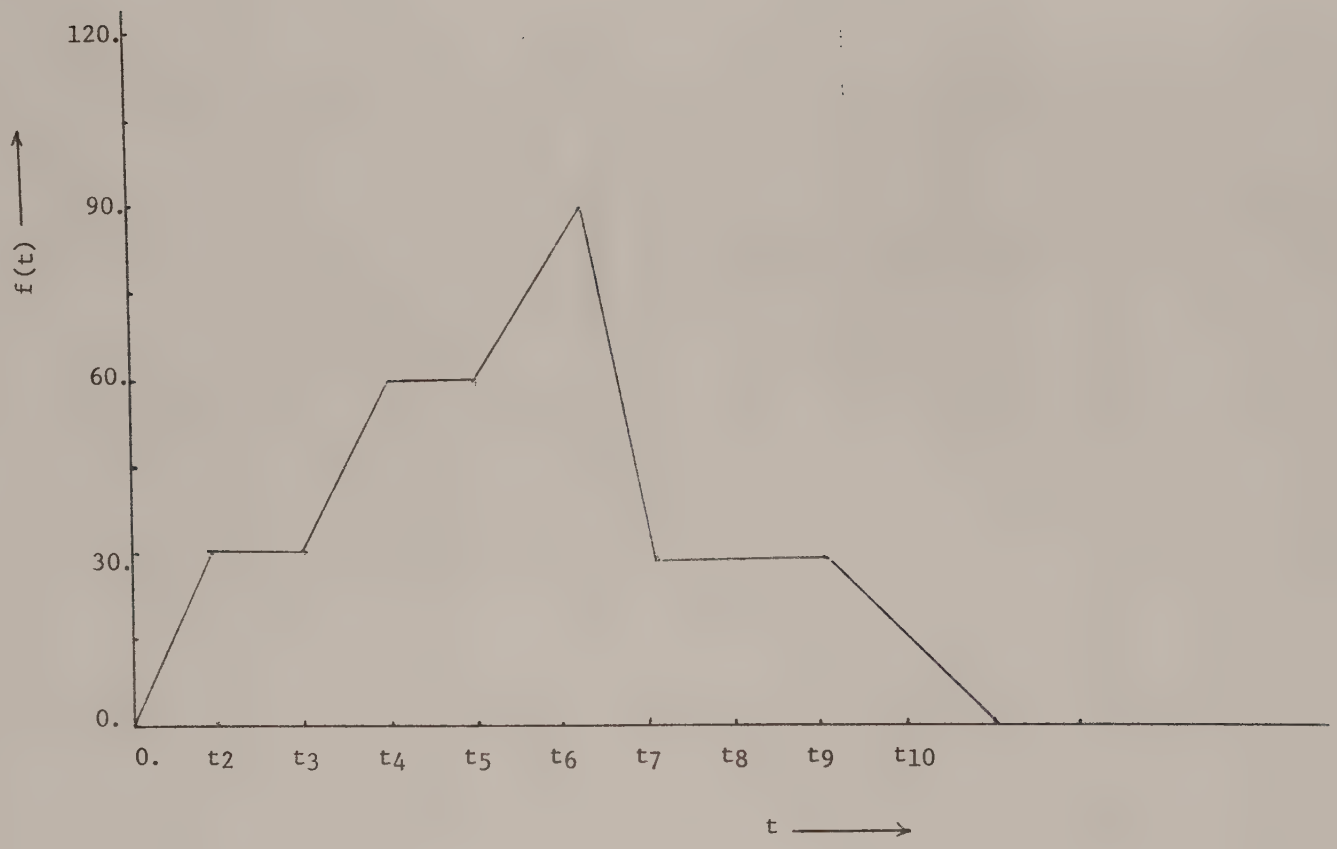


Figure 3.--Time dependence of f(t).

B. Input Deck Format

The format for the input deck necessary to run a BFISH analysis is shown in Figure 4, which is discussed in the following paragraphs.

1. Model structure

The first two cards of any BFISH input deck set up the model structure. Referring to Figure 4, we have:

NSP = number of species ($\leq$ 3)

NCM = number of compartments ($\leq$ 50)

NCY = number of cycles to be modeled

NST = Number of timesteps per cycle

H = length of each timestep

NMC = number of managed compartments ($\leq$ NCM)
(= number of compartments in the management area)

MOPT = management option
(= 1, 2, or 3)

ILAG = lag time (in timesteps) between the target fish distribution and the commercial fishing fleet distribution (= 0 or 1), used only if MOPT = 2 or 3

IMIG = $\begin{cases} 1 \rightarrow \text{continuous migration coefficient functions} \\ 2 \rightarrow \text{piecewise constant migration coefficient functions} \end{cases}$

Figure 4.--BFISH input format.

MODEL STRUCTURE INPUTS:

1-3	4-6	7-9	10-12	13-23	24-34	35-45	46-50
NSP	NCM	NCY	NST	H			
NMC	MOPT	ILAG					
IMIG	IQC	IQS					
IKEY	IKS_1	IKS_2	IKS_3				
IYKEY	IYS_1	IYS_2	IYS_3				

IF MOPT = 1

____ FOR EACH COMPARTMENT (i = 1 to NCM): COMMERCIAL FISHING EFFORT INPUTS

1-3	4-6	7-9	10-12	13-23	24-34	35-45	46-50
	C_i	T_i	0^1	$coefficients^1$ →			
			cd^2	$nodal\ values^2$ →			

IF MOPT = 2:
TOTAL COMMERCIAL FISHING EFFORT INPUTS:

1-3	4-6	7-9	10-12	13-23	24-34	35-45	46-50
		T	0^1	$coefficients^1$ →			
			cd^2	$nodal\ values^2$ →			

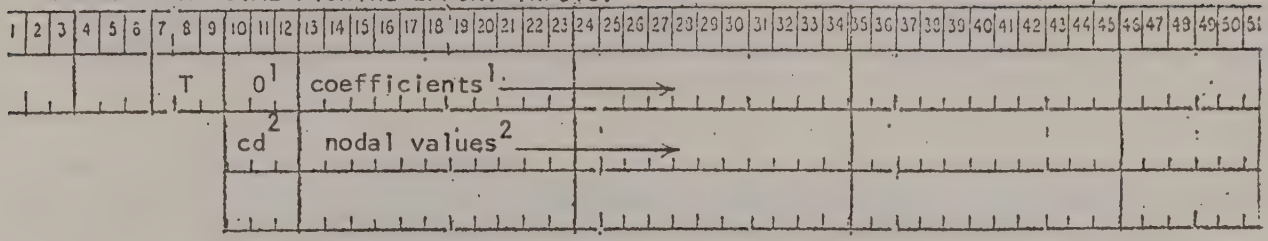
____ FOR EACH MANAGED COMPARTMENT (k = 1 to NMC): EFFORT CEILING INPUTS

1-3	4-6	7-9	10-12	13-23	24-34	35-45	46-50
	C_k	T_k	0^1	$coefficients^1$ →			
			cd^2	$nodal\ values^2$ →			

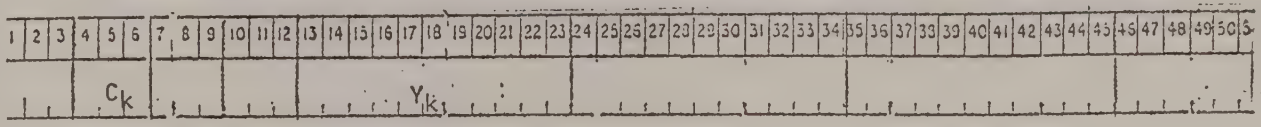
Figure 4.--Continued.

IF MOPT = 3:

TOTAL COMMERCIAL FISHING EFFORT INPUTS:



FOR EACH MANAGED COMPARTMENT (k = 1 to NMC): YIELD CEILING



FOR EACH COMPARTMENT (i = 1 to NCM): SPORT FISHING EFFORT INPUTS

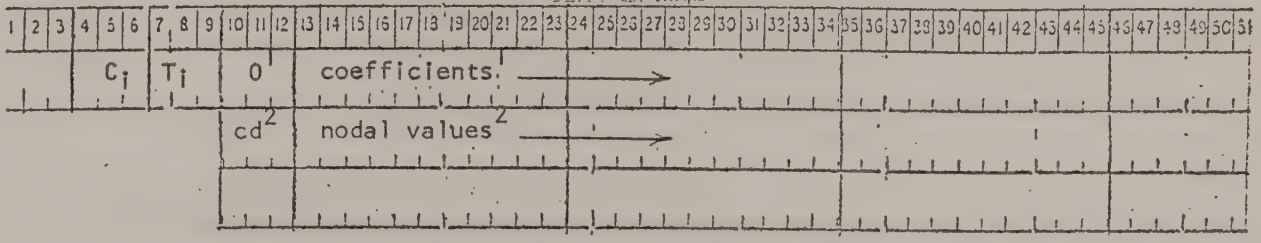


Figure 4.--Continued.

FOR EACH SPECIES (j = 1 to NSP):
RECRUITMENT AND NATURAL MORTALITY INPUTS:

2 3	4 5 6	7 8 9	10 11 12	13 14 15 16 17 18 19 20 21 22 23	24 25 26 27 28 29 30 31 32 33 34	35 36 37 38 39 40 41 42 43 44 45	46 47 48 49 50 51
S_j	$R1_j$	$R2_j$	m_j	RCINIT	RCMAX	XNMORT	

REPRODUCTION COEFFICIENT INPUTS

1 2 3	4 5 6	7 8 9	10 11 12	13 14 15 16 17 18 19 20 21 22 23	24 25 26 27 28 29 30 31 32 33 34	35 36 37 38 39 40 41 42 43 44 45	46 47 48 49 50
		T_j	0^1	coefficients[1] →			
			cd^2	nodal values[2] →			

FOR EACH COMPARTMENT (i = 1 to NCM):
COMMERCIAL FISHING CATCHABILITY COEFFICIENT INPUTS:

1 2 3	4 5 6	7 8 9	10 11 12	13 14 15 16 17 18 19 20 21 22 23	24 25 26 27 28 29 30 31 32 33 34	35 36 37 38 39 40 41 42 43 44 45	46 47
	C_i	T_{ij}	0^1	coefficients[1] →			
			cd^2	nodal values[2] →			

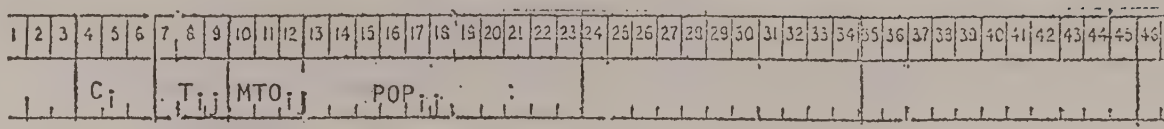
FOR EACH COMPARTMENT (i = 1 to NCM):
SPORT FISHING CATCHABILITY COEFFICIENT INPUTS

1 2 3	4 5 6	7 8 9	10 11 12	13 14 15 16 17 18 19 20 21 22 23	24 25 26 27 28 29 30 31 32 33 34	35 36 37 38 39 40 41 42 43 44 45	46 47
	C_i	T_{ij}	0^1	coefficients[1] →			
			cd^2	nodal values[2] →			

Figure 4.--Continued.

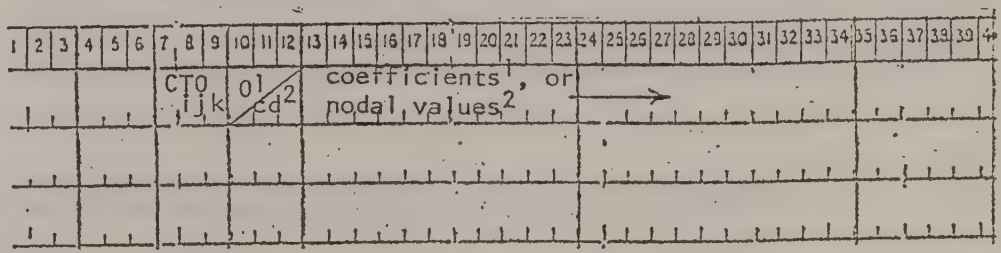
FOR EACH COMPARTMENT (I = 1 to NCM):

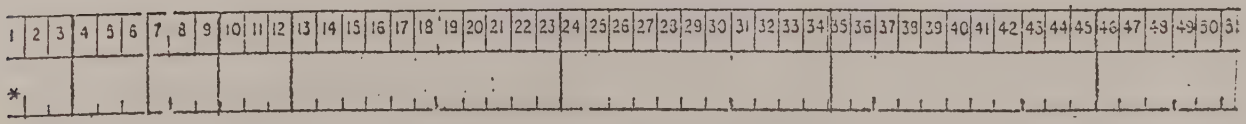
MIGRATION INPUTS



FOR EACH COMPARTMENT MIGRATED TO (k = 1 to MTO_{ij})

MIGRATION COEFFICIENT INPUTS:





$$IQC = \begin{cases} 1 \rightarrow \text{continuous commercial fishing catchability coefficient functions} \\ 2 \rightarrow \text{piecewise constant commercial fishing catchability coefficient functions} \end{cases}$$

$$IQS = \begin{cases} 1 \rightarrow \text{continuous sport fishing catchability coefficient functions} \\ 2 \rightarrow \text{piecewise constant sport fishing catchability coefficient functions} \end{cases}$$

IKEY = number of species in target fish population (≤ 3), used only if MOPT = 2 or 3

IKS_i = species number of the i^{th} target species (i = 1 to IKEY)

IYKEY = number of species in the managed population, i.e., those species that will count toward the commercial yield limit (≤ 3), used only if MOPT = 3

IYS_i = species number of the i^{th} managed species (i = 1 to IYKEY)

Only the commercial fishing yield is counted toward the yield limit. Thus, if we want the commercial fishing fleet to key on a target population consisting of the summed population of three different species, but our management scheme calls for an upper limit on the number of fish that can be taken commercially from species number 2 only within our management area, we would set MOPT = 3, NSP = 3, IKEY = 3, $IKS_1 = 1$, $IKS_2 = 2$, $IKS_3 = 3$, IYKEY = 1, $IYS_1 = 2$.

2. Commercial fishing effort and ceiling inputs

This section of the input deck follows the model structure cards, and will differ in format for different management options. The three alternative (and mutually exclusive) formats are:

a) If MOPT = 1, the commercial fishing effort must be supplied for each compartment separately. Referring to Figure 4, we define:

C_i = compartment number

T_i = type of representation (1 or 2, for polynomial or explicit representation, respectively)

0 = order of the polynomial

cd = card number

The superscript 1 denotes variables that are only required if T = 1, and the superscript 2 denotes variables that are only required if T = 2. The first NMC compartments listed will constitute the management area. No special calculation will take place for the managed compartments, but separate population and yield subtotals will be kept for the management area. Compartment numbers must range from 1 to NCM, but need not be listed in order. If T = 2 for any compartment, NST nodal values must be listed, four to a card. Obviously, if NST > 4, there will be more than one card involved in supplying all NST nodal values. Each of these cards is numbered.

b) If MOPT = 2, the user must supply the total commercial fishing effort function and, for each managed compartment, the effort ceiling function. Effort ceiling inputs must be supplied for NMC compartments. Any compartment number not specified in the effort ceiling input set is assumed to be out of the management area (and hence has no effort ceiling). Thus, if NCM = 10 and NMC = 3, three effort ceiling functions must be supplied. Suppose the three C_k supplied are 4, 7, and 9. Then compartments 4, 7, and 9 constitute the management area. Compartments 1, 2, 3, 5, 6, 8, and 10 are unmanaged. If T = 1, 0 for the effort ceiling function must be ≤ 4.

c) If MOPT = 3, the total commercial fishing effort function is again required. In addition, the user must supply the yield ceiling placed on each managed compartment. This is a single quantity, not a function, and is specified by Y_k for compartment C_k in Figure 4. If the total commercial fishing yield (of the species specified as managed species) in compartment C_k ever exceeds Y_k during any one time cycle, commercial fishing effort in C_k is set to zero for the remainder of the cycle.

3. Sport fishing effort inputs

For each compartment, the sport fishing effort function is specified.

4. Species dependent inputs

The following input requirements describe the species dependent inputs for a single species. The species number for each set is specified as the first card of the set. NSP such sets must be supplied, one for each species.

a) Recruitment and natural mortality

Referring to Figure 4, the following definitions are made:

S_j = species number

$R1_j$ = first timestep in the recruitment period for species S_j

$R2_j$ = last timestep in the recruitment period for species S_j

m_j = maturation age (in number of cycles) for species S_j

$RCINIT_j$ = initial recruitment rate (constant recruitment rate for the first m_j cycles) for species S_j

$RCMAX_j$ = maximum recruitment rate for species S_j

$XNMORT_j$ = natural mortality coefficient for species S_j

b) Reproduction coefficient

The reproduction coefficient function is supplies for species S_j. Note that this function is only evaluated during the recruitment period for species S_j, and hence must only be valid on the interval (t_{F1_j}, t_{R2_j+1}).

S_j = species number

$R1_j$ = first timestep in the recruitment period for species S_j

$R2_j$ = last timestep in the recruitment period for species S_j

m_j = maturation age (in number of cycles) for species S_j

XN_j = natural mortality coefficient for species S_j.

b) Reproduction coefficient

The reproduction coefficient function is supplies for species S_j. Note that this function is only evaluated during the recruitment period for species S_j, and hence must only be valid on the interval (t_{R1_j}, t_{R2_j+1}).

c) Commercial fishing catchability coefficient

This variable is both species and compartment dependent. The commercial catchability coefficient function is supplied for each compartment C_i for each species S_j.

d) Sport fishing catchability coefficient

This function is supplied for each compartment C_i for each species S_j.

e) Migration coefficients

The format for these inputs differs slightly from the other functional inputs. For each species S_j a migration set is described for each compartment C_i. Referring to Figure 4, the following definitions apply:

T_{ij} = type of function representation for species S_j and compartment C_i (= 1 or 2).

MTO_{ij} = the number of different compartments that species S_j migrates to from compartment C_i during the course of a time cycle (≤ 8).

POP_{ij} = initial population of species S_j in compartment C_i.

Then, for k = 1, MTO_{ij}, the migration coefficient functions are supplied, where:

CTO_{ijk} = the compartment number of the k^{th} compartment migrated to by species S_j from compartment C_i.

If T_{ij} = 1, CTO_{ijk} is followed by the order of the polynomial and the polynomial coefficients to describe the time dependence of the migration coefficient for species S_j migrating from compartment C_i to compartment CTO_{ijk}. If T_{ij} = 2, card number one of the nodal set follows on the same card as CTO_{ijk}. If additional cards are required (NST > 4), CTO_{ijk} is repeated on each card in addition to supplying the card number and the next 4 nodal values.

5. End of file

A star ('*') is placed in column one of an otherwise blank card to denote the end of the input data for the BFISH program. This card is placed immediately after the last card in the input deck, but before any additional record or file marks required by the operating system.

C. Rules for coding

BFISH is written in FORTRAN, and there are some characteristics common to most FORTRAN compilers that are relevant to the input file format. Specifically:

1. Right adjust all integer variables. FORTRAN will add zeroes to fill up the field. For example, if the species number, $S_j = 3$, is punched in column 2 instead of column 3 of the appropriate input card, BFISH will read it as $S_j = 30$. Thus, all values appearing in the four integer fields (columns 1-3, 4-6, 7-9, and 10-12) should be right adjusted.

2. Blanks are interpreted as zeroes. Thus, leaving any field blank is equivalent to giving that variable a value of zero.

3. Decimals must be supplied to fixed decimal inputs. It is possible, but not probable, that the value will be interpreted correctly if the decimal is omitted. The issue can be avoided by supplying decimals in the proper places in all values punched in fixed decimal fields (columns 13-23, 24-34, 35-45, 46-56, 57-67, and 68-78).

V. OUTPUT

A. Echo Check

The first section of the BFISH output file is a complete list of all the input parameters with each value associated with its function in the program. These values should be carefully checked to see if the user's intentions have been accurately transmitted to the BFISH model. It is expected that most of the problems that arise in using the model will be at the input level, and the echo section of the output should be scrutinized for accuracy each time the model is employed.

BFISH reads in the nodal points of explicitly represented variables, in groups of 4, as they are needed during execution. Thus, not all points are kept in storage (if NST > 4) at any one time. These nodal points are printed out as they are read. The first four points appear in the echo section. Any additional points are identified and printed out as they are read during execution. Thus, the timestep output may be intermittently interrupted to print out sets of nodal points as they are needed.

B. Timestep Output

The timestep output is printed out at the end of each timestep. This is an important consideration, as BFISH contends with discontinuous functions (e.g., commercial fishing effort when MOPT = 2 or 3) and discontinuous first derivatives (e.g., any explicitly represented variable) across timestep boundaries. The values printed at time t are consistent with an incremental approach to t from the negative side (i.e.,

are equivalent to the appropriate values at time $(t - \varepsilon)$ where ε is arbitrarily small).

First the time is identified by the following four variables:

ICYCLE = time cycle number

ISTEP = timestep number within this cycle

TIME = time expired within this cycle

TTOTAL = total time expired

The fishing population and yield outputs are then presented for each species in turn. Within each species set, the fishing efforts, catchability coefficients, recruitment rates, populations, and yields are printed for each compartment. In addition, the Collatz coefficient, S, is printed for each compartment for the calculation just completed. This coefficient is defined by equation (8), and should be used as a measure of the appropriateness of the timestep size. If the population gradient is zero, equation (8) will be undefined, and S is set equal to -1.

Each species set continues with a printout of the population and yields summed over all compartments and summed over the management area. Cycle-to-date yields are also calculated and printed. These outputs are repeated for each species at the end of each timestep.

VI. SYNOPSIS OF ROUTINES

BFISH was constructed in modular form to facilitate program updates. This type of construction yields many function and subprogram subroutines, each isolating a separate calculational step. The relationships between the constituent routines are shown in Table 1. These routines are listed and briefly described below:

A. Main Driver

The main driver serves as the focal point for the BFISH modules. The main procedure steps through time, performing the Runge-Kutta and yield integration over each timestep. An outline of the main driver program flow appears in Figure 5.

B. Function EVAL

Function EVAL evaluates a specified function at a specified time. This function is called to calculate the values of the time dependent coefficients at specific times during the time cycle. An outline of the EVAL program flow appears in Figure 6.

C. Function PRIME

Function PRIME evaluates the first time derivative of a specified function at a specified time. This function is called to calculate the first derivatives of time dependent coefficients necessary to carry out the yield function integrations. An outline of the PRIME program flow appears in Figure 7.

Table 1.--Routine hierarchy in BFISH.

Function or program	Calls	Is called by
MAIN	DATIN READ4 SUMGRT EFFORT EVAL XGRATE RPOP RCRUIT PRIME POPDOT RSOLVE	
EVAL	POLY	MAIN EFFORT XGRATE
PRIME	POLY	MAIN
POLY		EVAL PRIME
XGRATE	EVAL RPOP	MAIN
RSOLVE		MAIN
SUMGRT		MAIN
RPOP		MAIN XGRATE
POPDOT		MAIN
RCRUIT		MAIN
EFFORT	EVAL	MAIN
DATIN	SKIP	MAIN
READ4	FIND	MAIN
FIND	SKIP	READ4
SKIP		FIND

Figure 5.--Main program outline.

I. Initialize variables.

II. For each timestep:

A. For each species:

1. For each compartment:

a. Calculate XK1

b. Store the beginning-of-timestep commercial and sport fishing yield function values for later integration.

2. Store the beginning-of-timestep reproduction function value for later integration.

3. For each compartment, calculate XK2.

4. For each compartment, calculate XK3.

5. For each compartment:

a. Calculate XK4.

b. Calculate end-of-timestep opulation.

6. For each compartment:

a. Calculate end-of-timestep commercial and sport fishing yield function values.

b. Integrate the commercial and sport fishing yield functions over the timestep.

7. Calculate the end-of-timestep reproduction function value and integrate the reproduction function over the timestep.

8. If this is the last timestep in the recruitment period, push the RSTACK array and calculate the recruitment function coefficients for next cycle.

B. Increment counters and zero out step totals.

Figure 6.--Function EVAL outline.

I. Branch to the appropriate function.

II. Branch to the appropriate type of representation.

    A. If TYPE = 1:

        1. Evaluate the polynomial at time t.

        2. Return.

    B. If TYPE = 2:

        1. Evaluate the function as if it were linear across the timestep.

        2. Return.

Figure 7.--Function PRIME outline.

I. Branch to the appropriate function.

II. Branch to the appropriate type of representation.

    A. If TYPE = 1:

        1. Evaluate the first derivative of the polynimial at time t.

        2. Return.

    B. If TYPE = 2.

        1. Evaluate the first derivative of the function as if the function was linear (first derivative constant) across the timestep.

        2. Return.

D. Function POLY

Function POLY evaluates an arbitrary polynomial in time given the polynomial coefficients and the time.

E. Function XGRATE

Given some arbitrary function values $f(t_1)$, $f'(t_1)$, $f(t_2)$, and $f'(t_2)$, XGRATE uses the Taylor series method described earlier to calculate and return the value of the integral:

$$\text{XGRATE} = \int_{t_1}^{t_2} f(t)dt$$

F. Subroutine RSOLVE

Subroutine RSOLVE takes the stored reproduction data for a given species and time cycle and calculates the coefficients of a polynomial in time that describes the recruitment rate to the species due to spawning activity during the stored cycle.

G. Subroutine SUMGRT

Subroutine SUMGRT calculates (see equation 1), for some specific species and time t:

$$\text{EMIGRT}_i(t) = \sum_{i \neq k} \text{XM}_{i \to k}(t)$$

$$\text{SMIGRT}_i(t) = \sum_{i \neq k} \text{XM}_{k \to i}(t) * P_k(t)$$

H. Function RPOP

Function RPOP returns the augmented population values necessary to calculate the Runge-Kutta coefficients.

I. Function POPDOT

Function POPDOT evaluates equation (1) given the necessary coefficients.

J. Function RCRUIT

For a given species, RCRUIT divides up the total recruitment rate among the various compartments.

K. Subroutine EFFORT

Subroutine EFFORT calculates and distributes the commercial fishing effort among the various compartments based upon the user selected management option. An outline of the EFFORT program flow appears in Figure 8.

L. Subroutine DATIN

Subroutine DATIN makes the initial read from the input file. An outline of the DATIN program flow appears in Figure 9.

M. Subroutine READ4

Subroutine READ4 is called to read the next four nodal points of the explicitly represented variables when they are required. An outline of the READ4 program flow appears in Figure 10.

Figure 8.--Subroutine EFFORT outline.

I. If MOPT = 1, return.

II. If MOPT = 2:

A. For each compartment:

1. Distribute the total effort based upon the proportion of the total target population that resided in the compartment at the beginning of the last timestep.

2. Check to see if the effort ceiling has been exceeded:

a. If no, continue.

b. If yes, set effort = ceiling and accumulate excess effort.

B. If excess effort $\leq$ 0, or if number of iteration > 10, return.

C. If excess effort > 0 and number of iterations $\leq$ 10:

1. Set total effort to be distributed = excess effort.

2. Set total target population = the sum of the target populations in those compartments that have not reached their effort ceiling.

3. Go back to (II.A) for next iteration.

D. Return.

III. If MOPT = 3:

A. Sum up the total target population in those compartments that have not yet reached their yield limit.

B. Distribute the effort to those compartments that have not yet reached their yield limit based upon the fraction of the total target population that resided in each compartment at the beginning of the last timestep.

C. Return.

Figure 9.--Subroutine DATIN outline.

I. Transfer input data to file 3.

II. Read model structure inputs.

III. Branch to appropriate management option inputs.

  A. If MOPT = 1: for each compartment, read the commercial fishing effort inputs.

  B. If MOPT = 2 or 3:

    1. Read total commercial fishing effort inputs.

    2. For each compartment, read ceiling inputs.

IV. For each compartment, read sport fishing effort inputs.

V. For each species:

  A. Read reproduction coefficient inputs.

  B. For each compartment, read commercial fishing catchability coefficient inputs.

  C. For each compartment, read sport fishing catchability coefficient inputs.

  D. For each compartment:

    1. Read number of compartments migrated to.

    2. For each compartment migrated to, read migration coefficient inputs.

Figure 10.--Subroutine READ4 outline.

I. Rewind file 3.

II. Branch to the appropriate management option inputs.

A. If MOPT = 1: for each compartment, read the next four nodes of the explicitly represented commercial fishing effort inputs.

B. If MOPT = 2 or 3:

1. If total commercial fishing effort is explicitly represented, read the next four nodes.

2. For each compartment, read the next four nodes of the explicitly represented ceiling inputs.

III. For each compartment, read the next four nodes of the explicitly represented sport fishing effort inputs.

IV. For each species:

A. If the reproduction coefficient is explicitly represented, read the next four nodes.

B. For each compartment, read the next four nodes of the explicitly represented commercial fishing catchability coefficient inputs.

C. For each compartment, read the next four nodes of the explicitly represented sport fishing catchability coefficient inputs.

D. For each compartment:

1. Read number of compartments migrated to and type of representation for migration coefficients.

2. If explicitly represented: for each compartment migrated to, read the next four nodes of the migration coefficient inputs.

N. Subroutine FIND

Subroutine FIND finds a specified card among the input cards for an explicitly represented variable, reads the card, and skips to the end of the card set for that variable.

O. Subroutine SKIP

Subroutine SKIP skips a specified number of cards on the input file.

VII. VARIABLE DEFINITION LIST

The following is an alphabetically arranged definition list of the major variables in the BFISH model.

B: The difference between the end-of-timestep and beginning-of timestep values of a function being evaluated in subroutine EVAL.

C (I, J, ICMPT, ISPEC):

1) If ICTYPE (I, ICMPT, ISPEC) = 1, C(I, J, ICMPT, ISPEC) holds the J^{th} polynomial coefficient, for species ISPEC in compartment ICMPT, for (if I = 1) the commercial fishing catchability coefficient or (if I = 2) the sport fishing catchability coefficient.

2) If ICTYPE (I, ICMPT, ISPEC) = 2, C(I, J, ICMPT, ISPEC) holds four nodal values (J = 3 to 6) from the input explicit representation, for species ISPEC in compartment ICMPT, for (if I = 1) the commercial fishing catchability coefficient or (if I = 2) the sport fishing catchability coefficient.

CARD: A character array (80 character capacity) used in subroutine DATIN to transfer input records from file 5 to file 3.

COEF: Used in subroutine SUMGRT to store the migration coefficient between two specified compartments at a specified time.

COEFS (I): Used in subroutines EVAL and PRIME to store the I^{th} coefficient of the specific polynomial function being evaluated.

DUMMY: An array used to transfer four nodal values of some explicitly represented variable between subroutine FIND and subroutine READ4.

E (I, J, ICMPT):

1) I = 1, MOPT = 1:

   a) IETYPE (1, ICMPT) = 1: E(1, J, ICMPT) holds the J^{th} polynomial coefficient for the commercial fishing effort function in compartment ICMPT.

   b) IETYPE (1, ICMPT) = 2: E(1, J, ICMPT) holds four nodal values (J = 3 to 6) from the input explicit representation for the commercial fishing effort in compartment ICMPT.

2) I = 1, MOPT = 2:

   a) ICLTYP (ICMPT) = 1: E(1, J, ICMPT) holds the polynomial coefficients (J = 2 to 6) for the commercial fishing effort ceiling function in compartment ICMPT. The commercial fishing effort in compartment ICMPT for the present time-step is stored in E(1, 1, ICMPT).

   b) ICLTYP (ICMPT) = 2: E(1, J, ICMPT) holds four nodal values (J = 3 to 6) from the input explicit representation for the commercial fishing effort ceiling in compartment ICMPT. The commercial fishing effort in compartment ICMPT for the present timestep is stored in E(1, 1, ICMPT).

3) I = 1, MOPT = 3: E(1, 2, ICMPT) holds the yield limit per cycle for managed species in compartment ICMPT. The commercial fishing effort in compartment ICMPT for the present timestep is stored in E(1, 1, ICMPT).

4) I = 2:

   a) IETYPE (2, ICMPT) = 1: E(2, J, ICMPT) holds the J^{th} polynomial coefficient for the sport fishing effort function in compartment ICMPT.

   b) IETYPE (2, ICMPT) = 2: E(2, J, ICMPT) holds four nodal values (J = 3 to 6) from the input explicit representation for the sport fishing effort in compartment ICMPT.

EC: Commercial fishing effort.

ECDOT: First time derivative of the commercial fishing effort function.

EM: The sum of the migration coefficients out of a specific compartment.

EMIGRT (ICMPT): The sum of the migration coefficients out of compartment ICMPT.

ES: Sport fishing effort.

ESDOT: First time derivative of the sport fishing effort function.

EXCESS: Used in subroutine EFFORT (when MOPT = 2) to store the excess effort accumulated during one iteration that must be distributed on the next iteration.

F1: The beginning-of-time-interval value of some function that is to be integrated.

F1DOT: The beginning-of-time-interval first derivative of some function that is to be integrated.

F2: The end-of-time-interval value of some function that is to be integrated.

F2DOT: The end-of-time-interval first derivative of some function that is to be integrated.

FP2: The estimate for the second time drrivative of some function, evaluated at the beginning of a time interval, for use in a Taylor series expansion of the function across the time interval.

FP3: The estimate for the third time derivative of some function, evaluated at the beginning of a time interval, for use in a Taylor series expansion of the function across the time interval.

FP4: The estimate for the fourth time derivative of some function, evaluated at the beginning of a time interval, for use in a Taylor series expansion of the function across the time interval.

FRAC (ICMPT): The fraction of the beginning-of-timestep population of a given species that resides in compartment ICMPT.

FRACP: The fraction of the total target population that resided in a given compartment at the beginning of the previous timestep.

H: Length of one timestep.

IBEGIN: The nodal array location containing the beginning-of-timestep value of an explicitly represented variable.

IC: Input card (record) number.

ICARD: The input card (record) number that contains the next four nodal values for the explicitly represented variables.

ICHECK: A check to see if the number of timesteps per cycle is a multiple of four.

ICLORD (ICMPT): The order of the polynomial representing the effort ceiling in compartment ICMPT (used only if ICLTYP (ICMPT) = 1).

ICLTYP (ICMPT): 1 or 2 for polynomial of explicit representation (respectively) of the effort ceiling function for compartment ICMPT.

ICMPT: Compartment number.

ICORDR (I, ICMPT, ISPEC):

1) I = 1: The order of the polynomial representing the commercial fishing catchability coefficient for species ISPEC in compartment ICMPT (used only if ICTYPE (1, ICMPT, ISPEC) = 1).

2) I = 2: The order of the polynomial representing the sport fishing catchability coefficient of species ISPEC in compartment ICMPT (used only if ICTYPE (2, ICMPT, ISPEC) = 1).

ICOUNT: An integer counter.

ICTYPE (I, ICMPT, ISPEC):

1) I = 1: 1 or 2 for polynomial or explicit representation, respectively, of the commercial catchability coefficient of species ISPEC in compartment ICMPT.

2) I = 2: 1 or 2 for polynomial or explicit representation, respectively, of the sport fishing catchability coefficient of species ISPEC in compartment ICMPT.

IEORDR (I, ICMPT):

1) I = 1: The order of the polynomial representing the commercial fishing effort in compartment ICMPT (used only if IETYPE (1, ICMPT) = 1).

2) I = 2: The order of the polynomial representing the sport fishing effort in compartment ICMPT (used only if IETYPE (2, ICMPT) = 1).

IETYPE (I, ICMPT):

1) I = 1: 1 or 2 for polynomial or explicit representation, respectively, of the commercial fishing effort in compartment ICMPT.

2) I = 2: 1 or 2 for polynomial or explicit representation, respectively, of the sport fishing effort in compartment ICMPT.

IF: Function index: 1 or 2 for commercial fishing or sport fishing functions, respectively.

IFIRST (ISPEC): The first timestep in the recruitment period for species ISPEC.

IFUNC: Function number where

1 = reproduction coefficient

2 = recruitment rate

3 = commercial fishing effort

4 = sport fishing effort

5 = commercial catchability coefficient

6 = sport catchability coefficient

7 = migration coefficient

8 = effort or yield ceiling

9 = total commercial fishing effort

IGO: Branching index.

IKEY: The number of target species in the target population for commercial fishing effort (used when MOPT = 2 or 3).

IKSPEC(I): Species number of the I^{th} species in the target population (I = 1 to IKEY).

ILAG: The lag time (in timesteps) between the target species distribution and the commercial fishing effort distribution (= 0 or 1).

ILAST (ISPEC): The last timestep in the recruitment period for species ISPEC.

IMIG: The migration coefficient option where

1) IMIG = 1, the migration coefficients are treated as continuous functions of time.

2) If IMIG = 2, the migration coefficients are treated as piecewise constant functions of time.

IMORDR (ICMPT, ITO, ISPEC): Order of the polynomial used to represent the migration coefficient for species ISPEC from compartment ICMPT to compartment MCMPT (ICMPT, ITO, ISPEC) (used only if IMTYPE (ICMPT, ISPEC) = 1).

IMTYPE (ICMPT, ISPEC): 1 or 2 for polynomial or explicit representation, respectively, of the migration coefficient(s) for species ISPEC leaving compartment ICMPT.

IQC: Commercial fishing catchability coefficient option, where

1) If IQC = 1, the commercial fishing catchability coefficients are treated as continuous functions of time.
2) If IQC = 2, the commercial fishing catchability coefficients are treated as piecewise constant functions of time.

IQS: Sport fishing catchability coefficient options, where

1) If IQS = 1, the sport fishing catchability coefficients are treated as continuous functions of time.
2) If IQS = 2, the sport fishing catchability coefficients are treated as piecewise constant functions of time.

IRCRUT (ISPEC): = 1 if the present timestep is part of the recruitment period for species ISPEC; = 0 otherwise.

IREAD: The timestep number before which the next four nodal values for explicitly represented variables must be read.

IRFLAG: = 0 if no variable is explicitly represented; = 1 otherwise.

IRORDR (I, ISPEC):

1) 1: The order of the polynomial describing the reproduction coefficient for species ISPEC (used only if IRTYPE (1, ISPEC) = 1).

2) I = 2: The order of the polynomial describing the recruitment rate for species ISPEC (will always = 4).

IRP1: A counter usually equal to the number of coefficients in a polynomial.

IRTYPE (I, ISPEC):

1) J = 1: 1 or 2 for polynomial or explicit representation, respectively, of the reproduction coefficient for species ISPEC.

2) I = 2: 1 always since the recruitment rate for species ISPEC is always generated by BFISH as a polynomial.

IS: An integer counter.

ISKIP: An integer argument equal to the number of cards (records) that are to be skipped on the input file.

ISPEC: Species number.

ISTEP: Timestep number.

ISTOP: Integer variable = MATURE (ISPEC).

IT: Integer variable indexing a compartment migrated to.

ITER: Iteration number.

ITO: Integer counter indexing a compartment migrated to.

ITORDR: The order of the polynomial representing the total commercial fishing effort (used only if ITTYPE = 1).

ITST: An array of timestep numbers.

ITTYPE: 1 or 2 for polynomial or explicit representation, respectively, of total commercial fishing effort.

IYKEY: Number of managed species in the managed population (used only when MOPT = 3).

IYSPEC (I): Species number of the I^{th} species in the managed population (I = 1 to IYKEY).

MATURE (ISPEC): Age (in cycles) at which members of species ISPEC enter the fishery.

MCMPT (ICMPT, ITO, ISPEC): Compartment numbers to which members of species ISPEC migrate from compartment ICMPT (ITO = 1, MTO (ICMPT, ISPEC))

MFLAG (ICMPT): = 1 if compartment ICMPT is in the management area; = 0 otherwise.

MOPT: Management option, where

MOPT	DESCRIPTION
1	Externally (user) supplied commercial fishing effort
2	Commercial fishing effort internally generated subject to user supplied effort ceilings
3	Commercial fishing effort internally generated subject to user supplied yield limits

MT (ICMPT, ISPEC): The number of different compartments migrated to from compartment ICMPT by species ISPEC.

NCARD: The number of input cards (records) necessary to explicitly represent each node in a time cycle. Hence, each explicitly represented variable (TYPE = 2) will have a set of NCARD input records associated with it.

NCMPT: The number of compartments being modeled in the present analysis.

NCYCLE: The number of time cycles being modeled in the present analysis.

NLAST: The array location holding the last node of the set of explicit nodal values currently in storage.

NMAX: The total number of timesteps that will be modeled during the present analysis.

NMCMPT: The number of managed compartments being modeled in the present analysis.

NORDER: Order of a polynomial being evaluated.

NSPEC: The number of species being modeled in the present analysis.

NSTEP: Number of timesteps per cycle.

NUMBER: An integer variable usually used to store the value of MTO (ICMPT, ISPEC).

P: Population.

PDOT: First time derivative of the population of a given species in a given compartment.

PDOTOT: The sum of PDOT over all compartments.

PMANAG: The sum of the populations of a given species over all managed compartments.

POP (ICMPT, ISPEC): Population of species ISPEC in compartment ICMPT.

PTARGT (ICMPT): The target population in compartment ICMPT.

PTOT (ISPEC): The population of species ISPEC summed over all compartments.

QC: Commercial fishing catchability coefficient.

QCDOT: First time derivative of the commercial fishing catchability coefficient.

QS: Sport fishing catchability coefficient.

QSDOT: First time derivative of the sport fishing catchability coefficient.

R (I, J, ISPEC):

1) I = 1: R(1, J, ISPEC) holds either the polynomial coefficients (in J = 1 to 6) or nodal values (in J = 3 to 6), for IRTYPE (1, ISPEC) = 1 or 2 respectively, for the reproduction coefficient for species ISPEC.

2) I = 2: R(2, J, ISPEC) holds the polynomial coefficients (J = 1 to 5) for the 4th order polynomial describing the recruitment rate to species ISPEC.

R1: Beginning of timestep value of the reproduction function.

R1DOT: Beginning of timestep value of the first time derivative of the reproduction function.

RBAR (ISPEC): The integral of the reproduction function for species ISPEC over the recruitment period.

RC: Recruitment rate.

RCHECK (ISPEC): The maximum number of fish that can be recruited to species ISPEC in one timestep (= RCMAX (ISPEC) * timestep length).

RCINIT (ISPEC): The initial recruitment rate to species ISPEC, used for the first MATURE (ISPEC) time cycles.

RCMAX (ISPEC): The maximum recruitment rate for species ISPEC.

RDSAVE (ISPEC): Beginning of recruitment period value of the first time derivative of the reproduction function for species ISPEC.

RINTGL: The integrated recruitment rate over the present timestep.

RP: Reproduction coefficient.

RPDOT: First time derivative of the reproduction function.

RSAVE (ISPEC): Beginning of recruitment period value of the reproduction function for species ISPEC.

RSTACK (J, K, ISPEC): The stack of values used to calculate the recruitment coefficients for species ISPEC.

K (= 1 to MATURE (ISPEC)) = the number of cycles previous to the current cycle that the stored values represent.

J (= 1 to 5) =

J	DESCRIPTION
1	$f(t_1)$
2	$\dot{f}(t_1)$
3	$f(t_2)$
4	$\dot{f}(t_2)$
5	$\int_{t_1}^{t_2} f \, dt$

where

$f(t) = RP(T) * P_{TOTAL}(t)$

$RP(t)$ = reproduction coefficient for species ISPEC at time t

$P_{TOTAL}(t)$ = total population (summed over all compartments) for species ISPEC at time t

$\dot{f}(t) = \frac{df}{dt}$ evaluated at time t

The recruitment coefficients for species ISPEC in any cycle are calculated from a Taylor series expansion whose parameters are calculated from the 5 stored values RSTACK (J, MATURE(ISPEC), ISPEC), J = 1 to 5.

RTOT: Total recruitment rate for a specific species.

S(ICMPT): The Collatz sensitivity coefficient for the Runge-Kutta calculations for compartment ICMPT for a specific species.

SMIGRT (ICMPT): For a specific species, the sum of the products of the migration coefficients into compartment ICMPT and the populations of the contributing compartments, or

$$SMIGRT(i) = \sum_{i \neq j} XM_{j \to i} * P_j$$

$XM_{j \to i}$ = migration coefficient from compartment j to compartment i for a specified species and time.

P_j = population in compartment j of a specified species at a specified time.

STAR: An alphabetic variable (= *) used to denote the end of the input file.

SUM: = SMIGRT (ICMPT), used as a function subroutine argument.

T: Time.

TE(J):

1) If ITTYPE = 1, TE(J) holds the J^{th} polynomial coefficient for the total commercial fishing effort function.

2) If ITTYPE = 2, TE(J) holds four nodal values (J = 3 to 6) from the input explicit representation of the total commercial fishing effort.

TEFORT: Total commercial fishing effort.

TIME(J):

1) J = 1: beginning of timestep time

2) J = 2: middle of timestep time

3) J = 3: end of timestep time

TT: The total target fish population summed over compartments that have not yet reached their effort ceiling limit.

TTARGT: The total target fish population.

TTOTAL: Total time expired.

XK1 (ICMPT): First Runge-Kutta coefficient for compartment ICMPT and a specific species.

XK2 (ICMPT): Second Runge-Kutta coefficient for compartment ICMPT and a specific species.

XK3 (ICMPT): Third Runge-Kutta coefficient for compartment ICMPT and a specific species.

XK4 (ICMPT): Fourth Runge-Kutta coefficient for compartment ICMPT and a specific species.

XM (J, ICMPT, ITO, ISPEC):

1) If IMTYPE (ICMPT, ISPEC) = 1, XM (J, ICMPT, ITO, ISPEC) holds the J^{th} polynomial coefficient for the migration coefficient for migration of species ISPEC from compartment ICMPT to compartment MCMPT (ICMPT, ITO, ISPEC).

2) If IMTYPE (J, ICMPT, ITO, ISPEC) = 2, XM (J, ICMPT, ITO ISPEC) holds from nodal vales (J = 3 to 6) from the input explicit representation of the migration coefficient for migration of species ISPEC from compartment ICMPT to compartment MCMPT (ICMPT, ITO, ISPEC).

XNMORT (ISPEC): Natural mortality coefficient for species ISPEC.

XPOLY: Storage variable for a partially evaluated polynomial used in function subroutine POLY.

Y1: Used in subroutine EVAL to denote the beginning-of-timestep value of a function.

Y2: Used in subroutine EVAL to denote the end-of-timestep value of a function.

YC1 (ICMPT): The commercial yield function for compartment ICMPT evaluated at the beginning of the timestep.

YC1DOT (ICMPT): The first time derivative of the commercial yield function for compartment ICMPT evaluated at the beginning of the timestep.

YCMNG: Commercial fishing yield in the management area over a one timestep period.

YCMTOT (ISPEC): Cycle-to-date commercial fishing yield in the management area of species ISPEC.

YCSTEP (ISPEC): Total commercial fishing yield (summed over all compartments) of species ISPEC over a one timestep period.

YCTOT (ISPEC): Total cycle-to-date commercial fishing yield (summed over all compartments) of species ISPEC.

YIELDC: Commercial fishing yield.

YIELDS: Sport fishing yield.

YMANAG (ICMPT): Cycle-to-date yield of managed species in compartment ICMPT.

YS1 (ICMPT): The sport yield function for compartment ICMPT evaluated at the beginning of the timestep.

YS1DOT (ICMPT): The first time derivative of the sport yield function for compartment ICMPT evaluated at the beginning of the timestep.

YSMNG: The sport fishing yield in the management area over a one timestep period.

YSMTOT (ISPEC): Cycle-to-date sport fishing yield in the management area of species ISPEC.

YSSTEP (ISPEC): Total sport fishing yield (summed over all compartments) of species ISPEC over a one timestep period.

YSTOT (ISPEC): Total cycle-to-date sport fishing yield (summed over all compartments) of species ISPEC.

Z: Multiplier (= 0., 0.5, or 1.) used in subroutine EVAL when evaluating explicitly represented functions.

VIII. NOTES

A. BFISH backspaces, rewinds, and rereads the input file repeatedly during execution. This may cause laughter in the control room if the input unit happens to be a card reader. To avoid this, BFISH writes the entire input file to disc before starting its reads. To facilitate this, the user must make a disc file with logical unit number 3 available to the program before the execution step.

B. Increasing the number of species and compartments that may be modeled is as simple as increasing the dimensions of the appropriate arrays in the common blocks.

C. If you elect to use polynomials to represent any of the time dependent coefficients, be sure that you know what you are doing. At no time should any of the coefficients be negative. The BFISH program will be quite happy with negative coefficients, but the user may not be as content with the results of the analysis if fish migrate backwards or fishing fleets supplement the population by throwing fish into the water.

This non-negativity criterion holds, of course, for explicit representation (type 2) as well. But in this case the user can easily inspect the inputs for negative values.

A good personal rule would be to inspect a plot of each of your input polynomials before using it.

D. When the maximum recruitment rate ceiling, RCMAX, is imposed or lifted in the middle of a timestep, the Taylor series representation will try to match the resulting boundary conditions with a smooth function. This can lead to wild representations between time nodes. When the necessary information is then passed to subroutine RSOLVE to generate a recruitment function, a wildly oscillating function may result. This will manifest itself in unreasonable recruitment rates. Due to the nature of the calculations the end-of-cycle totals are usually realistic (the integrated functions are reasonable), but the interim timestep values for the recruitment rate may be negative, exceed RCMAX, or act in other suspicious ways. One example of how this condition may occur would be the combination of a large population and an end-of-timestep reproduction coefficient of zero. Thus, RCMAX will be imposed over most of the timestep, but eventually (as the reproduction function approaches zero) the RCMAX barrier will be broken and a large negative gradient will immediately ensue. This radical discontinuity would overtax a third order Taylor series. It is better to keep the reproduction coefficient positive and finite over the entire span of the recruitment period.

Note also that this will not manifest itself in the Collatz coefficient S. In fact, if the population gradient is purely a function of time, XK2 = XK3 and S = 0. The Runge-Kutta procedure is, in fact, probably performing admirably. It is the integrand that is unrealistic.

E. While it is not necessary, it would certainly be intuitively pleasing if the end-of-cycle coefficient values equal the beginning-of-cycle values ($f(t_F) = f(0)$). This is done by BFISH for explicit variables, but is up to the user for polynomials.

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National Oceanic and Atmospheric Administration
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TO ALL BILLFISHERS:

A little over 18 years ago Peter Fithian introduced his baby, the Hawaiian International Billfish Tournament (HIBT). When HIBT was just a 3-year old infant the National Marine Fisheries Service (NMFS) began sending biologists to the tournament to collect data on billfishes and other game fishes. In the ensuing years as Papa Peter nurtured his child and guided its growth, NMFS took on the role of a close uncle. That is, NMFS visited regularly and provided interesting contributions to the child's growth in the form of demonstrations, workshops, lectures, projects, and exhibits on game fish oriented science without having to be responsible for its basic needs and survival. In this role NMFS also issues a report on the biological and statistical aspects of the tournament. This is the report of the Nineteenth HIBT.

The work accomplished by NMFS at the tournament was possible through the great cooperation and willingness of the tournament staff and officials, the anglers, and the volunteers from the community. As this year's NMFS representatives, Ray Sumida and I sincerely thank you for your assistance and support. In the past we have been remiss in our acknowledgments by not singling out Peter Fithian and James Sutherland who, despite overseeing the myriads of details which go into organizing the HIBT, have consistently planned for our presence so that our work at the tournament is facilitated long before the tournament even starts.

THE CATCH

Eighty-seven fish were caught in this year's tournament. This number does not include the fish that were disqualified because of rule infractions. The catch consisted of 71 blue marlin, 14 ahi (yellowfin tuna), 1 striped marlin, and 1 shortbill spearfish. As can be seen from Table 1 this year's catch rate (all species combined) was the same as last year's. This year's 71 blue marlin, however, amounted to 51% more than last year's. In fact, this catch of 71 blue marlin ranks fifth among blue marlin catches of all the tournaments held to date.

The weights of the blue marlin ranged from 133 to 683 lb and averaged 231.4 lb. The weights of the ahi ranged from 108 to 223-1/2 lb and averaged 177.7 lb. The single striped marlin weighed 102-1/2 lb and the shortbill spearfish tipped the scales at all of 7 lb.

SEX

Last year for the first time in the history of HIBT more female blue marlin than male blue marlin were caught. This year the males resumed their foolish ways. Of the 66 blue marlin we examined 41 were males and 25 were females, a male:female ratio of 1.6:1 (Table 2). The data of past years suggested a correlation between catch rate and the male to female ratio. Each year as we added another data point we would do a correlation analysis. The correlation was never statistically significant but always tantalizingly close. It turns out we were looking at the wrong variable. The catch rate of blue marlin during a tournament is strongly correlated to the number of males caught in the tournament (Figure 1) and independent of the number of females.

FISHING AREAS

The data for the detailed analyses for this section were obtained from your reports during the radio roundups. The most popular area was Tango which totaled 367 boat-hours. Other well fished areas in order of popularity were: Juliett (284 boat-hours), Sierra (269 boat-hours), Uniform B and Kilo (263 boat-hours each). Other areas with over a hundred boat-hours of fishing were: Uniform A, Lima, Victor, and India. The analyses were limited to these nine areas.

Area Victor had the best strike rate of 0.22 strike per boat-hour. Uniform B was second with 0.16 strike per boat-hour. Kilo and India had strike rates of 0.13 strike per boat-hour. Tango had the most strikes for the tournament but it also had the most fishing effort. This area ranked fifth in strike rate. The overall strike rate for all the areas was 0.13 strike per boat-hour. This is a shade better than last year's 0.11 and considerably less than the 0.20 average of the previous 4 years. Figure 2 categorizes the areas according to their strike rates.

Table 3 summarizes the catch by areas, species, and dates. Area Tango yielded 11 blue marlin to lead all areas. Areas Sierra and Kilo were next with 10 and 9 blue marlin, respectively. When fishing effort is taken into consideration, however, India ranked first followed closely by Sierra, Kilo, and Victor in that order. The areas with the best marlin weight production were: Sierra (11.3 lb/boat-hour), India (10.9 lb/boat-hour), Kilo (8.6 lb/boat-hour), and Tango (8.5 lb/boat hour).

Uniform B and A were the best ahi areas with four and three ahi, respectively.

TACKLE, TIME, AND TIDE

Lines of two strengths, 24-kg test and 36-kg test, were used this year. These lines are the metric equivalent to the 50-lb and 80-lb test lines. The number of fish caught on these lines were close; 41 fish on the 24-kg line and 46 fish on the 36-kg line. A total of 8,439 lb was landed on the 24-kg line as compared to 11,692.5 lb on the 36-kg line. Translated into tournament points, the weight caught on the 24-kg line including its 50% bonus accounted for 966 points more than the catch on the 36-kg line.

There were 182 hook-ups in the tournament. Forty-eight percent of these resulted in the landing of a fish. A common question asked of us is, "What is the difference in losses of hook-ups between the two line strengths?" We don't have the answer to that because we only have line strength information of the fish that are landed. An analysis of the weights of blue marlin caught on these lines (Figure 3) is somewhat related to the question. Of marlins less than 200 lb, 22 were caught on 24-kg test line and 13 on 36-kg test. Of marlins between 200 and 500 lb, 10 were caught on 24-kg test line and 24 on 36-kg test. The two marlin over 500 lb were caught one on each type of line.

The best hour for catching blue marlin was 11 a.m. to noon (Figure 4). This is the third consecutive year that this hour has been the most productive in blue marlin. I have not investigated the hour of capture previous to HIBT 1975.

In Figure 5 the strike rates of each of the radio roundup periods for each day are superimposed on the tide chart. On the first 2 days of the tournament the best strike rates occurred on the rising tide. On the last 3 days the best strike rates occurred at low tide. On the last 3 days the low tide period coincided with the 11 a.m. to noon hour. You are invited to make your own interpretations of the facts.

MARLIN DIET

A list of the items found in the blue marlin stomachs (Table 4) contains 15 different fish families and squid. As usual members of the tuna family were the favorite items. They occurred in 69% of the stomachs examined.

Perhaps more interesting are the unusual facts about this year's stomach contents. Mahimahi were found in about twice as many stomachs than in the past. Three families of fish which had never occurred in HIBT marlin stomachs before were in this year's stomachs. These are the sand lance, snipe eel, and nehu. A flying gurnard showed up after an absence of 7 years and a goatfish after 4 years. The most unusual item was a tip of a marlin bill.

Until we meet again at the Twentieth Hawaiian International Billfish Tournament,

Aloha,

Heeny S. H. Yuen

Heeny S. H. Yuen
Leader, Recreational Fisheries

Attachments

October 31, 1977

Table 1.--Numbers of qualifying game fish landed and teams fishing during Hawaiian International Billfish Tournaments, 1962-77.

Year	Blue marlin	Black marlin	Striped marlin	Shortbill spearfish	Sailfish	Yellowfin tuna ≥100 lb	Total qualifying fish	Number of teams	Number of boat-days fishing per fish[1]
1962	30	1	--	--	1	19	51	68	6.7
1963	19	2	1	--	--	26	48	72	7.5
1964	31	--	1	--	--	2	34	69	10.1
1965	47	--	--	--	--	9	56	78	6.9
1966	26	3	2	--	--	7	38	72	9.5
1967	63	--	1	--	--	18	82	68	4.2
1968	36	2	4	--	--	4	46	85	9.2
1969	32	1	--	--	--	4	37	75	10.1
1970	91	--	2	--	2	14	109	73	3.3
1971	41	--	3	1	--	47	92	77	3.4
1972	77	--	--	--	--	11	88	59	3.4
1973	76	--	1	3	1	17	98	61	3.1
1974	66	2	1	6	--	37	110	64	2.9
1975	104	--	2	8	--	79	193	79	2.0
1976	47	1	3	5	--	32	88	74	4.2
1977	71	--	1	1	--	14	87	73	4.2

[1]Nine-hour fishing days, 1962-73; 8-h days, 1974-77.

Table 2.--Sex ratios for blue marlin examined from Hawaiian International Billfish Tournaments, 1962-77.

Year	Number of males	Number of females	Ratio males to females
1962	16	7	2.3:1
1963	13	6	2.2:1
1964	14	12	1.2:1
1965	35	8	4.4:1
1966	16	8	2.0:1
1967	51	13	3.9:1
1968	24	10	2.4:1
1969	23	8	2.9:1
1970	63	14	4.5:1
1971	21	9	2.3:1
1972	64	8	8.0:1
1973	47	21	2.2:1
1974	46	14	3.3:1
1975	70	16	4.4:1
1976	7	37	0.2:1
1977	41	25	1.6:1

Table 3.--Number of fish caught by species, date, and area, Hawaiian International Billfish Tournament, 1977.

Date, 1977	Area												
	B	C	D	I	J	K	L	M	S	T	U/A	U/B	V
Blue marlin													
August 15	—	—	1	3	1	2	—	1	3	3	1	1	—
16	—	—	—	—	2	2	1	—	—	1	2	—	—
17	—	2	—	2	1	3	1	1	2	4	1	1	4
18	—	—	—	1	1	1	1	—	4	—	3	5	1
19	—	—	—	1	1	1	1	—	1	3	—	—	—
Sum		2	1	7	6	9	4	2	10	11	7	7	5
Average weight (lb)		133.8	421.5	212.6	184.7	249.8	194.5	174.0	305.3	282.1	180.6	265.9	290.4
Ahi													
August 15	—	—	—	—	—	—	—	—	—	—	2	1	—
16	—	—	—	—	—	—	—	—	—	1	—	—	—
17	2	—	—	—	—	—	2	—	—	—	—	—	—
18	—	—	—	—	—	—	—	—	—	—	1	3	—
19	—	—	—	—	—	1	—	—	—	1	—	—	—
Sum	2					1	2			2	3	4	
Average weight (lb)	131.0					200.5	190.8			206.0	197.5	167.9	
Striped marlin													
August 15	—	—	—	—	1	—	—	—	—	—	—	—	—
Weight (lb)					102.5								
Shortbill spearfish													
August 16	—	—	—	—	—	—	—	—	—	—	—	—	1
Weight (lb)													7.0

Table 4.--Stomach contents of blue marlin, Hawaiian International Billfish Tournament, 1977

Food items	Date and number of stomachs containing listed food items					Percent occurrence
	August					
	15	16	17	18	19	
Fish						
Tunas and mackerels, Scombridae	10	6	14	11	3	69
Skipjack tuna, Katsuwonus pelamis	7	3	5	5	3	36
Kawakawa, Euthynnus affinis	--	1	--	--	--	2
Frigate mackerel, Auxis sp.	2	2	3	4	--	28
Unidentified tuna	5	3	7	11	--	41
Opelu, Carangidae	5	3	5	2	3	28
Mahimahi, Coryphaenidae	1	2	3	2	--	13
Triggerfish, Balistidae	1	2	2	4	--	14
Pelagic spiny puffer, Diodontidae	5	--	1	2	1	14
Butterflyfish, Chaetodontidae	--	--	1	1	--	3
Surgeonfish, Acanthuridae	--	--	1	--	--	2
Aweoweo, Priacanthidae	--	--	1	--	--	2
Goatfish, Mullidae	--	1	--	--	--	2
Nehu, Engraulidae	--	1	--	--	--	2
Flying gurnard, Dactylopteridae	1	--	--	--	--	2
Snake mackerel, Gempylidae	1	1	1	1	--	6
Snipe eel, Nemechthyidae	--	1	--	--	--	2
Bonnetmouth, Emmelichthyidae	--	2	--	--	--	3
Sand lance, Ammodytidae	--	--	1	--	--	2
Unidentified fish	4	4	6	2	1	27
Invertebrates						
Squid, Decapoda	4	2	5	--	--	17
Empty or everted stomachs	2	--	1	3	1	11
Number of stomachs examined	12	9	21	15	7	
Total: 64						

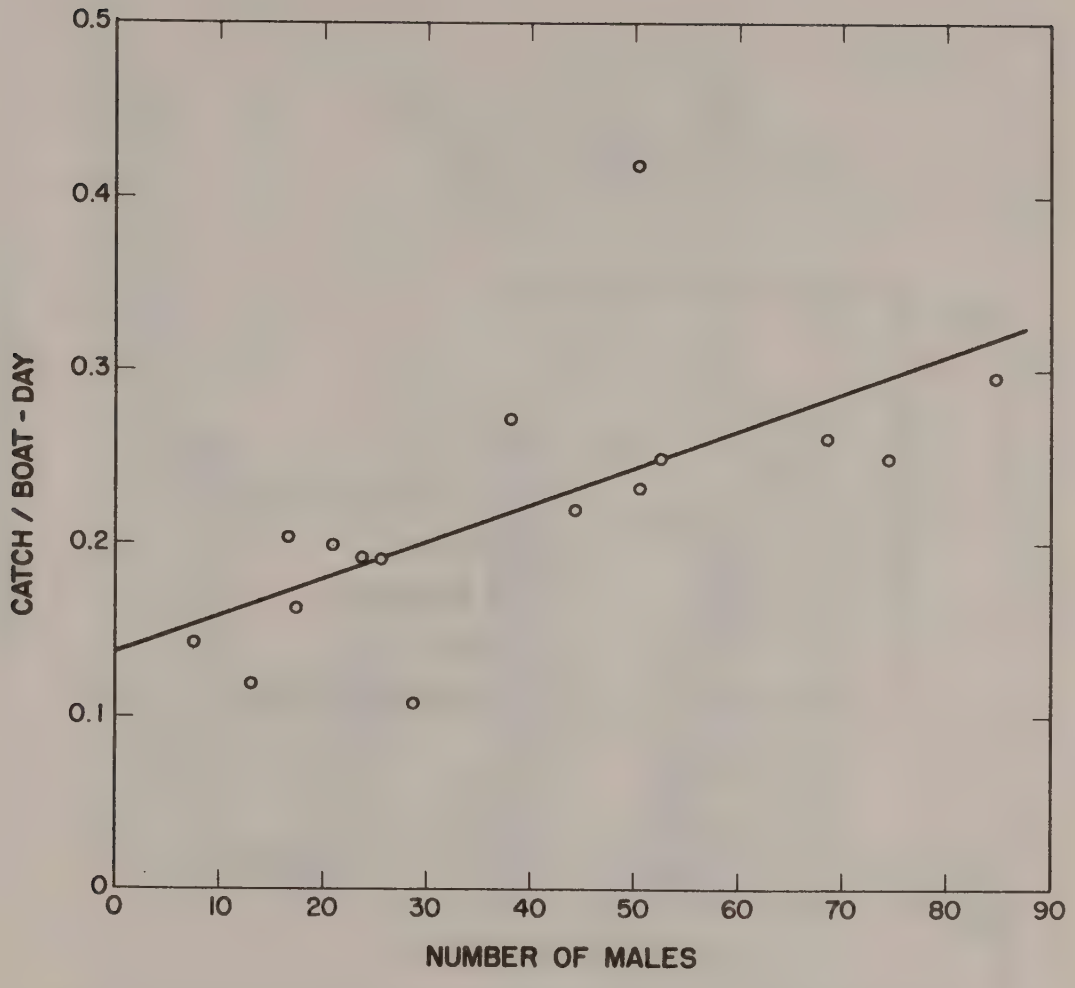

Figure 1.--The relationship of the catch rate of blue marlin to the number of males caught.

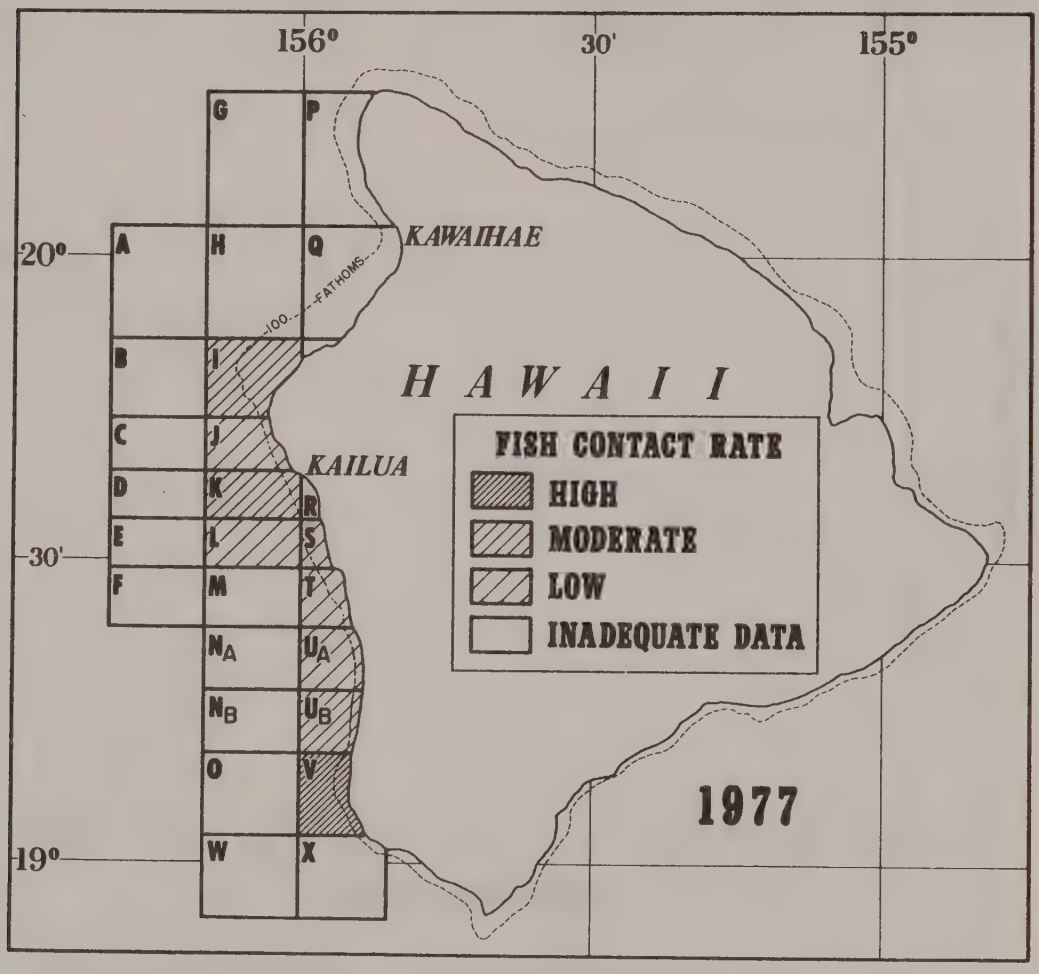

Figure 2.--Strike rate in various fishing areas.

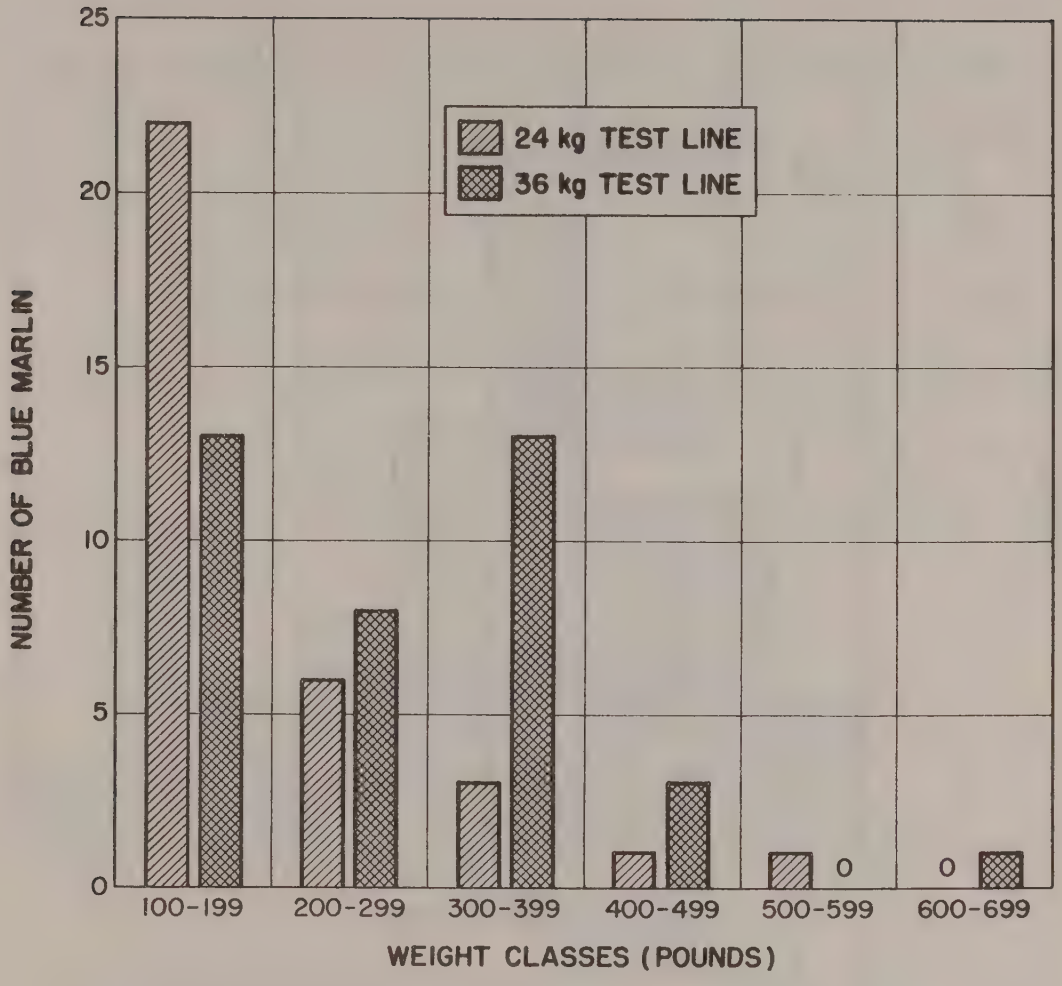

Figure 3.--Weights of blue marlin caught on 24- and 36-kg test lines.

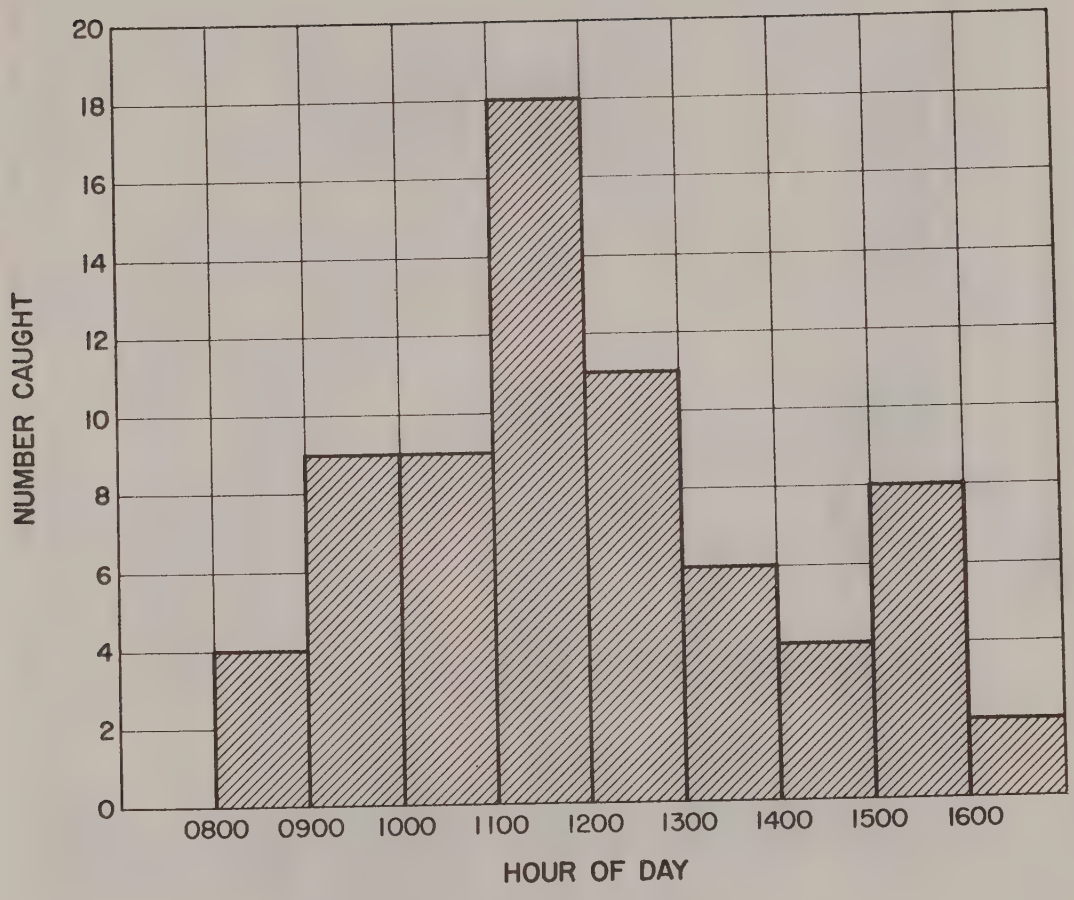

Figure 4.--Number of blue marlin caught at various hours of the day.

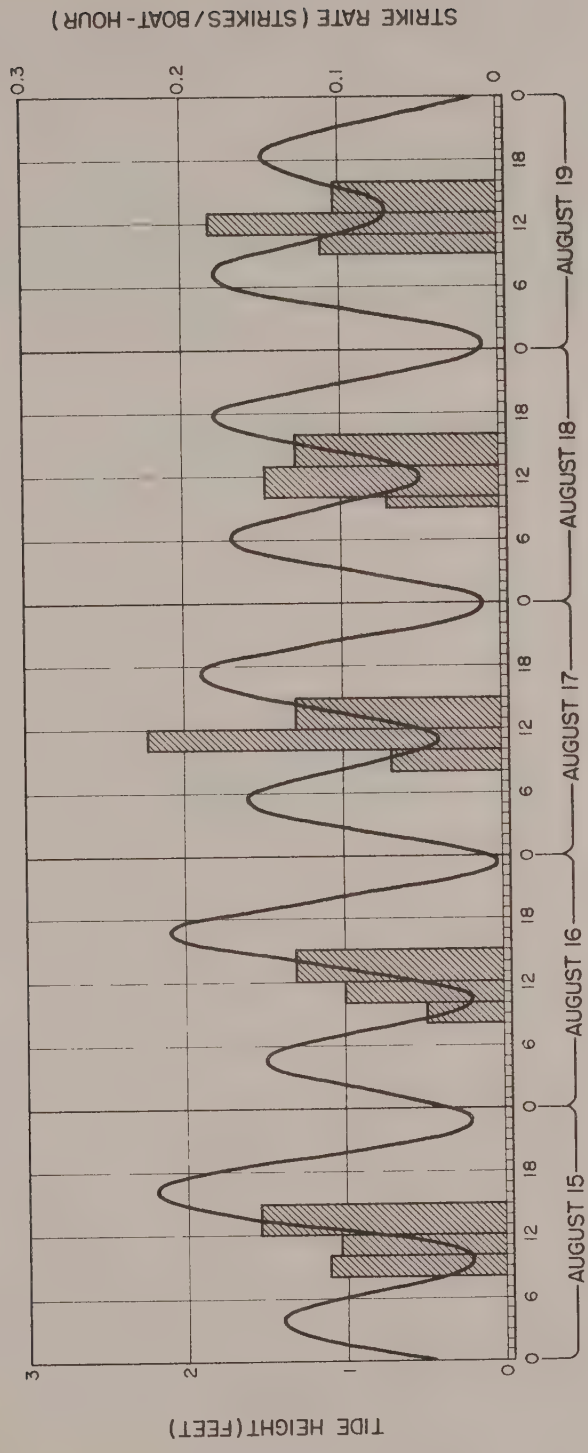

Figure 5.--Strike rates and tide cycle, HIBT 1977.

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A REVIEW OF THE STATUS OF THE HAWAIIAN MONK SEAL, MONACHUS SCHAUINSLANDI, AND DESIGNATION OF CRITICAL HABITAT

By

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A REVIEW OF THE STATUS OF THE HAWAIIAN MONK SEAL, MONACHUS SCHAUINSLANDI, AND DESIGNATION OF CRITICAL HABITAT

BACKGROUND

On 22 July 1976 the National Marine Fisheries Service, in concurrence with Marine Mammal Commission recommendations, designated the Hawaiian monk seal, Monachus schauinslandi, as a depleted species under the Marine Mammal Protection Act (Federal Register, Volume 41, No. 2). On 23 November 1976 the National Marine Fisheries Service, pursuant to Section 4 of the Endangered Species Act of 1973, listed the monk seal as an endangered species (Federal Register 41(227), 23 November 1976).

In December 1976, as provided for by Section 7 of the Endangered Species Act of 1973, the Marine Mammal Commission submitted to the National Marine Fisheries Service specific recommendations for the protection of the Hawaiian monk seal.

The present report (1) reviews the history of the monk seal, (2) details recent research efforts, (3) outlines recommendations made for designation of critical habitat, and (4) provides the current view of the Honolulu Laboratory on the subject of critical habitat.

HISTORY

The Hawaiian monk seal is endemic to the Hawaiian Archipelago. Only rarely are animals seen in the main high islands located southeast of Nihoa. To date, there have been no historical or archaeological evidence which indicates that the monk seal inhabited the main islands in significant numbers. All historical evidence indicates that in recent times the breeding populations of monk seal have been confined to six islands and atolls of the Northwestern Hawaiian Islands: Kure, Midway, Pearl and Hermes Reef, Lisianski, Laysan, and French Frigate Shoals. In 1976 breeding was reported for the first time at Necker Island; pups were observed on Necker during the 1976 and 1977 breeding seasons.

Nothing in the historical record indicates that the monk seal population in the Northwestern Hawaiian Islands was ever very large. There are relatively few references to the Monk seal but with one exception those who visited the islands during the 19th century reported that the animal was common but not numerous. An exception to the above was mentioned by Bryan (1915). Bryan noted that an expedition by the vessel Gambia was reported to have returned to Honolulu in 1859 with 1,500 seal skins and 240 barrels of seal oil. Based on this evidence, it would seem that seals must have been very numerous at that time. Since monk seals are easily approached by man, and are known to haul out at relatively few areas along the chain, it seems quite possible that the Gambia succeeded in exterminating a

large percentage of the total population during that single voyage. Even as early as 1824, a sealing expedition by the brig, Aiona, was thought to have taken the last seal. Thus, in accordance with the situation which prevailed with so many species during the 19th century and into the early 20th century, man's relationship with the Hawaiian monk seal does not seem to have been conducive to the well-being of the seal population. By the turn of the century the monk seal may have been very close to extinction and the species has possibly managed to survive only because of the isolation of its oceanic habitat and the cessation of sealing.

By 1912 the population had begun to recover; however, the seal was still reported to be very rare (Bailey 1952).

We have no information as to the degree of man's presence in the Northwestern Hawaiian Islands during the first half of this century. It was undoubtedly much greater than has been recorded; however, it probably is safe to say that there was relatively little deliberate killing of seals during this period. The seal population increased as reported by several expeditions which made counts on various islands. None of these expeditions, however, estimated the total Hawaiian population.

RECENT RESEARCH

When studies of seal populations were begun in 1957-58 (Kenyon and Rice 1959), breeding colonies were reported to be flourishing at four areas: Kure Island, Pearl and Hermes Reef, Lisianski, and Laysan Islands, and were also present at Midway Islands and French Frigate Shoals. Rice (1960) estimated the total Hawaiian population for the 1957-58 period at approximately 1,350 animals.

During the Kenyon and Rice survey, the U.S. Navy occupied Midway Islands and the U.S. Coast Guard occupied Tern Island in French Frigate Shoals. Human habitation in these areas continues to the present. In 1960 a U.S. Coast Guard loran station manned by about 20 men was established on Kure Island.

Kenyon (1972) made surveys of Kure and Midway Islands in 1968, 1969, and 1971 and found that where 68 seals were seen in 1957 and 1958 at Midway Islands, only 1, 4, and 6 were seen in 1968, 1969, and 1971. He observed that prior to Coast Guard occupation the majority of the monk seals used Green Island (site of the existing loran station) as pupping and hauling grounds. In 1968, few seals came ashore on Green Island; instead, they used isolated shifting sand spits which lacked sheltering vegetation. Kenyon's population surveys for Kure were limited, but the data indicated that the population may have suffered a considerable decline since 1957 and 1958. Kenyon concluded that intolerance of man induces changes in monk seal distribution and is

an important factor in reducing survival of young monk seals. Thus, according to Kenyon, population loss on these islands can be attributed to man. He observed that the amount of human disturbance that monk seals can tolerate without causing population damage is unknown but it appears that daily disturbance by man and dogs on small breeding islands is beyond the monk seal's critical threshold of tolerance.

Recent censuses conducted in cooperative efforts by the National Marine Fisheries Service and the Fish and Wildlife Service (DeLong et al. 1976; DeLong and Brownell 1977) and the Marine Mammal Commission confirms that there have been large population declines at Kure and Pearl and Hermes. At Midway Islands in 1976 a single adult was observed on the Spit Islands. In 1977, in apparent response to the closure of the Spit Islands by the U.S. Navy to all personnel, five seals were present, including an adult female with a pup. On the basis of 1976 and 1977 censuses, the populations on Lisianski and Laysan seem to have remained relatively stable. It is important to note, however, that the 1977 census estimated the population of Laysan at 178 animals, whereas a more reliable estimate by Brian and Patricia Johnson (National Marine Fisheries Service and Marine Mammal Commission researchers), who spent 7 months (February-September) during 1977 on Laysan, put the Laysan population at about 250 animals (pers. commun. with the Johnsons, September 1977). Whether this means that the population of Laysan was indeed much larger or that there is significant seal movement between islands or perhaps animals coming in from a pelagic existence remains to be determined by future research.

The results of recent research cruises indicate that the population on French Frigate Shoals may be increasing; 195 animals were sighted in 1976 and 223 in the 1977 survey.

Perhaps as dramatic as the decline of monk seals at Pearl and Hermes Reef is the increase of animals counted at Necker Island between 1976 (1 seal) and 1977 with a total of 46 seals (counts by the Fish and Wildlife Service between 1964 and 1969 ranged from 6 to 20). Even more significant are observations which confirm that pupping did occur at Necker during the 1977 season despite the limited and precarious haul-out areas. It is doubtful that Necker will ever become a major pupping area. The large 1977 count at Necker Island and the apparent increase at French Frigate Shoals does seem to furnish possible evidence of a shift of the center of population down the Hawaiian Archipelago.

The available information on the biology and stock assessment of the Hawaiian monk seal is inadequate to make more than generalized statements and to propose hypotheses about its population structure and its role in the ecosystem. A brief summary of our knowledge would include the following:

1. Population size.--There is general consensus that the present population of monk seals numbers less than 1,500 animals.

2. Population trends.--The sparse census data are inadequate to denote total population trends. While there has been a marked decline in numbers of animals on some islands (Midway Islands and Kure Islands) which are inhabited, a similarly marked decline has also been noted on Pearl and Hermes Reef, which is uninhabited. Thus, while human habitation may be a factor, the variation in animal counts throughout the chain suggests a more complex situation exists.

3. Productivity.--Little information exists on the reproductive rate, growth rate, longevity, or the natural mortality rate of monk seals. There is some evidence that sharks are one of the main predators of the seals, especially the young.

4. Migration.--Recent observations by Brian and Patricia Johnson give some information on the movements of monk seals on Laysan Island and its nearshore waters. Very little is known about the movement of monk seals beyond the outer reefs and in offshore waters. The observation of a seal tagged on Laysan Island and later reported on Johnston Island (547 nautical miles from Laysan) suggests that the monk seal is capable of relatively long-range movements (Schreiber and Kridler 1969).

5. Feeding habits.--A comprehensive study of the feeding habits of the monk seal has not been undertaken to date. Based on limited observations of material regurgitated by the monk seals and a reported visual underwater observation of a feeding monk seal, it appears that spiny lobsters represent one component in the diet of the monk seal. Other organisms identified from monk seal spewings include octopus, moray and conger eels, and other reef fishes.

CRITICAL HABITAT

There is general consensus that the Hawaiian monk seal needs some measure of protection. It is an endemic species with a very small current population size. Further, being on the endangered species list, it is mandatory that attention be directed to this animal in order to avoid man-induced extinction of the species. While mankind has been responsible for some species becoming extinct, e.g., the passenger pigeon, it should be recognized and emphasized here that in the natural course of evolution, organisms are continuously achieving species status or becoming extinct. In general the intent of society is that mankind does not unduly hasten the demise of a species.

In any consideration of critical habitat for the Hawaiian monk seal, the question arises: What is critical habitat according to the law? Then more specifically, what is the critical habitat for the

monk seal? The Federal Register, Volume 40, No. 78, 22 April 1975, defines critical habitat as: "For the continued viability of any species, suitable habitat is not only important but essential to life itself. The term 'habitat' could be considered to consist of a spatial environment in which a species lives and all elements of that environment including, but not limited to, land and water area, physical structure and topography, flora, fauna, climate, human activity, and the quality and chemical content of the soil, water, and air. Critical habitat for any endangered or threatened species could be the entire habitat, or any portion thereof, if, and only if, any constituent element is necessary to the normal needs or survival of that species. The following vital needs are relevant in determining 'critical habitat' for a given species:

(1) Space for normal growth, movements, or territorial behavior;

(2) Nutritional requirements, such as food, water, minerals;

(3) Sites for breeding, reproduction, or rearing of offspring;

(4) Cover or shelter; or,

(5) Other biological, physical, or behavioral requirements.

"The primary intention of the Fish and Wildlife Service and the National Marine Fisheries Service under the Endangered Species Act of 1973 is to protect, maintain, and restore presently endangered and threatened species to a point at which they are no longer endangered or threatened.

"Application of the term 'critical habitat' may not be restricted to the habitat necessary for a minimum viable population. It is emphasized further that certain actions may not be detrimental to 'critical habitat.' There may be many kinds of actions which can be carried out within the 'critical habitat' of a species that would not be expected to result in such reduction in the numbers or distribution or otherwise adversely affect such species."

Mr. Keith M. Schreiber, Endangered Species Program Manager with the U.S. Fish and Wildlife Service (Endangered Species Technical Bulletin, date unknown), in response to queries relative to the meaning of critical habitat, and its potential effects stated: "The most important point I can make about critical habitat is that in no way does it place an iron curtain around a particular area; that is, it does not create a wilderness area, inviolable sanctuary, or a sealed off area."

In March 1977 the National Marine Fisheries Service generated a report (Nitta 1977) which evaluated and suggested modifications to

the Marine Mammal Commission's proposed designation of critical habitat for the Hawaiian monk seal. In essence the report by Nitta concurred that (1) all areas in the Northwestern Hawaiian Islands utilized by the Hawaiian monk seal as breeding and pupping grounds be designated critical habitat, to include coral and beaches and attendant vegetation and the waters of the inner reef areas; (2) except for authorized scientific use, the Hawaiian Islands National Wildlife Refuge (HINWR) remain closed to all human activity including, but not limited to, commercial and sport fishing operations with access and use of Tern Island in French Frigate Shoals controlled by existing Coast Guard and HINWR regulations specifically developed for that area; and commercial fisheries not be excluded from the rest of the Northwestern Hawaiian Islands because we have no indication that the development of offshore fisheries outside of the lagoon areas will compromise the protection and/or recovery of the monk seals. Since the State of Hawaii is responsible for regulating these fisheries, we recommend that they be consulted prior to implementing any proposed recommendations or regulations concerning the Northwestern Hawaiian Islands; (3) Tern Island, French Frigate Shoals, be included in any designation of critical habitat, and the Coast Guard regulations currently in effect there be continued.

In the interim period and up to the present, there has been a great deal of controversy regarding the designation of critical habitat for the monk seal. It is clear, however, that events have progressed to a stage where in spite of limitations in our knowledge of many aspects of the biology of monk seals, critical habitat for the monk seal will be designated.

HONOLULU LABORATORY VIEWPOINT ON CRITICAL HABITAT

We agree with the general view that the Hawaiian monk seal should be afforded adequate protection despite the lack of a substantive body of scientific information. The critical question that surfaces is, "How much is adequate?" In developing the framework of a critical habitat recommendation, it would be best to review the conditions under which the animals presently exist. These are:

1. Virtually all of the islands of the Northwestern Hawaiian Islands represent potential haul-out and pupping grounds for the monk seal.

2. Human habitation in the Northwestern Hawaiian Islands include 1,500 U.S. Navy personnel and families at Midway Islands, 20 Coast Guard personnel on Kure Island and 23 Coast Guard personnel on Tern Island (French Frigate Shoals). We understand that there soon will be a considerable reduction of personnel on Midway and that the Coast Guard plans to phase out the French Frigate Shoals loran station by 1979-80.

In reviewing the Marine Mammal Commission's recommendation, it appears that the Commission argues the point that mankind, by his presence on the islands, has been responsible for the decline in

population of monk seals and thus the Commission made the recommendation that emerged land areas and waters out to 3 miles seaward of the islands be closed to human use. Excluded, however, were Kure, which does not fall within the HINWR, and Midway Islands. It appears that the Commission decided a priori that military needs and navigational safety were considerations that superseded the welfare of the monk seal. While this may be a realistic trade off, if one believes man's mere presence in the area is detrimental to the well-being of the monk seal, the only recourse to a first line recommendation should have been total banning of human habitation on all of the islands of the Northwestern Hawaiian Islands. The assessment of trade offs should then be made by other bodies responsible for these high-level decisions.

While current available knowledge suggests that the Hawaiian monk seal utilizes the lagoons and nearshore waters of the Northwestern Hawaiian Islands extensively, the 3-mile boundary recommendation appears to be untenable when one examines this recommendation based on available scientific data. Further, a 3-mile boundary for areas whose selection appears to be based on current human habitation begs the issue of critical habitat.

Considering the legal definitions of critical habitat and the virtual lack of information on the time and space distribution of the monk seal and the utilization by monk seals of waters outside of the immediate vicinity of the islands, our recommendations are:

Critical habitat designation for the Hawaiian monk seal should include:

1. All of the emerged lands of the Northwestern Hawaiian Islands.

2. All of the lagoon waters and the nearshore waters extending seaward out to the 10-fathom depth contour line. Access and usage of marine resources within the lagoon waters and nearshore waters out to the 10-fathom contour should include;

(a) Continued commercial and recreational usage of Midway Islands, Kure Island, and Tern Island (French Frigate Shoals) under the rules presently established by the governing agencies.

(b) Non-human use of the waters and resources within the lagoons and nearby waters extending out to the 10-fathom depth contour line of all of the islands of the Northwestern Hawaiian Islands not listed under (a) above. Exceptions will only include duly authorized scientific activity.

While the 10-fathom boundary in the critical habitat is based more on judgment rather than solid scientific data, we believe it does provide a measure of safety for the monk seal without placing undue restriction upon man's use of the outlying waters.

Finally, the Honolulu Laboratory recommends continued research on the Hawaiian monk seal; research which will permit better definition of the parameters of the monk seal's critical habitat. Emphasis should be on stock assessment, time and space movements of the monk seal, behavior, food and energetic studies, and habitat requirements. The results should lead to a better definition of the critical habitat, thus permitting reassessment of the restrictions implemented to safeguard the well-being of the Hawaiian monk seal.

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DRAFT FOR COMMENT

FISHERY DEVELOPMENT IN THE CENTRAL AND WESTERN PACIFIC ISLANDS OF U.S. CONCERN

NOV 9 1977

By

Richard S. Shomura[1]

Presently a number of organizations and agencies are engaged in various aspects of fishery development in the central and western Pacific. For those areas of U.S. concern, fishery development has assumed a new stature resulting from the passage of the Fishery Management and Conservation Act of 1976. The Act was directed towards optimum utilization of the marine resources within the 200-mile zone and the basic consideration was the desire to improve and enhance domestic fishing capabilities. Since resources that are not being fully utilized at an optimal level will be made available for harvesting by foreign fishing fleets, it is incumbent upon the U.S. domestic fishing industry to develop its own fisheries to its fullest extent.

The present report provides a brief review of ongoing fishery development activities in the central and western Pacific and some thoughts on areas of fishery development activities that should be considered for future support. The geographical areas covered in this report are those areas of direct concern to the U.S. and includes the Hawaiian Archipelago, American Samoa, Guam, and Northern Marianas, and the Trust Territory of the Pacific Islands.

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[1]Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, Hawaii 96812. November 1977.

FISHERY DEVELOPMENT - DEFINITION

For purposes of this report the term "fishery development" is defined as an activity which encompasses a wide range of research and development areas, all directed toward the utilization of a resource. The kinds of research and development specifics in fishery development include:

1. Assessment of resource

For those fisheries already in existence, the assessment would include evaluation of whether a resource base is capable of expanded production. For new resources the assessment and evaluation of the resource base should provide insights on whether the fishery should be directed toward commercial or recreational use, and define the full spectrum of economic benefits.

2. Harvesting

This category includes gear development, gear improvement, and fishing strategy. It also includes research directed toward specific biological problems, e.g., eliminating dependence on wild stocks for fry by developing induced spawning of a species under controlled conditions.

3. Processing

This category includes new product development, and improving existing processing technology.

4. Marketing

This category includes the wide spectrum of marketing.

The review of fishery development activities in the central and western Pacific area will be described in this report by area rather than general subject categories. Areas to be discussed include Hawaii, American Samoa, Guam, and Northern Marianas, and the Trust Territory of the Pacific Islands. For the resource categories, the breakdown is as follows:

1. Aquaculture
2. Inshore (lagoon and reef)
3. Slopes and banks
4. Pelagic

HAWAII

As shown in Figure 1 the Hawaiian Archipelago extends over a wide expanse of the central North Pacific area. The southeastern segment of the Archipelago consists of high volcanic islands which are inhabited. In general the reef areas and banks are not extensive. The fish fauna is typically Indo-Pacific and consist of approximately 680 species. Generally the abundance of any single species in the area is not considered to be very large. One exception is the skipjack tuna, Katsuwonus pelamis. The reported total annual catch of marine fishes in the State of Hawaii exclusive of tunas has averaged around 1,500 to 2,000 metric tons (MT). The skipjack tuna landings show a wide fluctuation from year to year, (roughly 3,000 to 8,000 tons);

the annual average is in the neighborhood of 4,500 tons. The ex-vessel value of all marine fish catches during the 1965-75 period ranged from $2.5 million to $5.2 million.

The northwestern half of the Hawaiian Archipelago consists of a few volcanic islands and series of low-lying atolls which extend northwest to Kure Island. Except for about 1,500 military personnel based on Midway Islands and 20 to 30 Coast Guard personnel stationed on French Frigate Shoals and Kure Island, the other islands and atolls of the Northwestern Hawaiian Islands are uninhabited. Also, except for Kure Island, the other islands of the Northwestern Hawaiian Islands are part of the Hawaiian Islands National Wildlife Refuge. With regard to fisheries, much of the slope and bank areas have not been fished heavily, if at all. An exception is the fishery on the Hancock Bank. Japanese and Soviet trawlers have fished the seamount resources of the Hawaiian Archipelago for the past decade. Presently the Honolulu Laboratory is engaged in a joint cooperative study to survey and assess the marine resources of the Northwestern Hawaiian Islands. Based on preliminary results it appears likely that a small fishery can be developed for lobsters and bottom fishes of the snapper and grouper type. Additionally, the kawakawa, Euthynnus affinis, resource appears to be large enough to support a small tuna fishery.

ONGOING FISHERY DEVELOPMENT ACTIVITIES

Table 1 summarizes the ongoing fishery activities in the State of Hawaii.

A brief review follows:

Aquaculture

The field of aquaculture is given very high priority in the State of Hawaii. The State Fish and Game Division devotes a major part of its aquaculture work toward developing a culture fishery for prawns, Macrobrachium rosenbergii. Other State aquaculture activities include (1) hatching eyed rainbow trout eggs obtained from mainland sources for a small recreational fishery on the island of Kauai, (2) hatching catfish for a recreational fishery based in the water reservoir system on Oahu. The University of Hawaii Sea Grant Program is actively working on various aspects of Macrobrachium prawns, e.g., genetics, and developing a suitable harvesting system, and (3) research to develop an algae industry in Hawaii. Finally, industry is directly involved in developing a culture fishery for catfish on the island of Maui, and oysters and Macrobrachium prawns on Oahu.

Inshore

The level of activity in this area is low and is confined to research of reef fishes.

Slopes and banks

The National Marine Fisheries Service (Honolulu Laboratory) is working on a development of spiny lobster fishery in the Northwestern

Hawaiian Islands. Also, exploratory work suggests that the finfish resource on the slopes and banks of the Northwestern Hawaiian Islands may be sufficiently large to support a small domestic fishery.

Pelagic

Activity is considered to be high in this area. Presently the Honolulu Laboratory is engaged in a cooperative undertaking with Pacific Islands Development Corporation to determine the effectiveness of anchored rafts to aggregate tunas. The Laboratory is also doing some work on stock assessment and economic research of the fishery for billfishes. Finally, the Laboratory is working on the problem of burnt tuna which is encountered by the handline fishery based on the island of Hawaii.

NEW FISHERY DEVELOPMENT PROJECTS

The following provides a preliminary list of fishery development projects that could be considered for support in forthcoming years. It should be noted that this list is not complete and is almost totally lacking in the identification of processing and marketing projects.

Aquaculture

1. Induced spawning of catfish. While this project relates to a fresh water resource, it is a problem that needs attention by some agency. A commercial industry for culturing catfish exists on the island of Maui. It has encountered a major stumbling block by not having access to a ready supply of fry. It is presently necessary

to buy fingerlings from the mainland. Efforts to date of inducing spawning of catfish in Hawaii have not been successful. The expertise in this area is lacking. Priority - high.

2. Development of a fishery for tropical aquarium fishes. Details of this project have been identified in a TDP submitted by the Honolulu Laboratory. Priority - high.

Inshore

1. Development of permanent artificial reef structures to enhance recreational fishing and possibly commercial fishing. Prior to embarking on a project of this nature, a detailed preliminary study should be undertaken to determine the need for artificial reefs. Priority - medium.

Slopes

1. Expand the handline fishery for tunas by exploring other areas in the Hawaiian Islands chain. Presently the fishery is confined to the island of Hawaii; however, there is no reason to suspect that other areas in the chain cannot be located which are suitable for this type of a fishery. Priority - high.

2. Ciguatoxin monitoring of locally-caught fishes. The University of Hawaii recently developed a rapid method to determine the level of ciguatoxin in fresh fish. While the ciguatoxin problem is not severe or critical in Hawaii, it would be desirable to monitor those species suspected to have high levels of ciguatoxin. Priority - medium.

Pelagic

1. Explore the Northwestern Hawaiian Islands for deepwater baitfish resources. Should a deepwater baitfish resource be located, the possibility of extending the Hawaiian pole-and-line fishery into the Northwestern Hawaiian Islands will be enhanced. Priority - high.

2. Develop a fishery for kawakawa in the Northwestern Hawaiian Islands. Recent observations from cruises into the Northwestern Hawaiian Islands suggest that the kawakawa resource in the Northwestern Hawaiian Islands may be large enough to support a small fishery. The project would entail using a commercial vessel to determine if commercial-size catches of kawakawa can be made.

AMERICAN SAMOA

The research and development activities that could be identified as fishery development for American Samoa are summarized in Table 2. As noted in the table, there is only a little effort in fishery development work going on in American Samoa today.

ONGOING FISHERY DEVELOPMENT ACTIVITIES

The following provides a summary of ongoing fishery development activities in American Samoa.

Aquaculture

This activity has been considered high and is confined to baitfish culture. As noted in Table 1, the Government of American Samoa (with support from NMFS via 88-309 funds), Sea Grant (University of Hawaii Sea Grant Program), and PTDF are working jointly to culture a sufficient supply of mollies to be used as baitfish for pole-and-line fishing of skipjack tuna in American Samoa. Basically the plan is to test the mollies as a suitable baitfish for catching skipjack tuna. Should the field trial succeed, efforts will be made to determine the suitability of developing a pole-and-line fishery in American Samoa based on the use of cultured baitfish.

Inshore

The immediate nearshore fishery resources in American Samoa are probably being harvested at a maximum level by the people of American Samoa. There is no fishery development activity in this area.

Slopes and banks

While the level of activity is rated high, this is a relative judgment. Much of the development efforts of the Government of American Samoa has been directed towards the dory fishery. No major effort has been provided recently to enhance the development of this fishery.

Pelagic

There is virtually no ongoing activity in the pelagic area of fishery development. There are, however, plans to move actively in this area.

NEW FISHERY DEVELOPMENT PROJECTS

The following provides a list of possible projects to be undertaken in American Samoa:

Aquaculture

Until the mollie field test is completed, no further projects in aquaculture are recommended.

Inshore

There may be a possibility to undertake a reef enhancement program in inshore waters of American Samoa. Whether some barren areas can be enhanced by artificial reefs needs to be explored further.

Slopes and banks

1. Improve the dory fishery by introducing the use of hydraulic reel systems in this fishery. Priority - high.

2. Explore the nearby banks and slopes of American Samoa for spiny lobster resources. Priority - high.

3. Conduct a ciguatoxin monitoring program utilizing the system developed by the University of Hawaii. This would be an extremely valuable project, since nearly one-half of the present catch made by the dory fishery is being discarded due to potential ciguatoxin problems. Priority - high.

Pelagic

1. Survey the deep waters of American Samoa for deepwater baitfish resources. Priority - high.

2. Develop a total systems approach to the development of a recreational fishery for billfishes and other pelagic species. Priority - high.

3. Develop a commercial and recreational fishery based around anchored aggregating devices. Priority - high.

GUAM AND NORTHERN MARIANAS

While Guam and the Northern Marianas are politically separate, for convenience, the two entities are considered collectively in this section. A summary of ongoing fishery development activities in the Guam and Northern Marianas areas is provided in Table 3.

Aquaculture

Presently a private firm is in the early stages of developing an eel, Anguille sp.,/on Guam. It has been reported that the financial industry backing comes from Taiwan. Not much else is known about the present status of this industry.

Inshore

There are no specific details available on the fishery development activities dealing with the inshore resources. Presumably effort is nil for the present.

Slopes and banks

Recent reports indicate that a private Japanese fishing company presently has an arrangement with some elements of the Northern Marianas government to conduct a survey of the bottom fish resources of the slopes and banks of the Northern Marianas. Presumably the development of a fishery would be for export to Japan.

Pelagic

Presently PTDF has a chartered purse seiner operating in the western Pacific. The vessel is operating out of Guam and recently offloaded a catch of about 600 tons of skipjack and yellowfin tunas.

NEW FISHERIES DEVELOPMENT PROJECTS

The following provides a list of potential projects:

Aquaculture

No projects proposed in the field of aquaculture.

Inshore

No projects proposed for inshore resources.

Slopes and banks

1. Develop a small multi-purpose vessel fishery for finfish resources located on the slopes and banks areas. Priority - high.

2. Explore the slopes and banks for spiny lobster resources. Priority - high.

Pelagic

1. Explore the feasibility of developing a skipjack fishery in the Northern Marianas. This would entail examining all of the aspects associated with developing a tuna fishery. Priority - high.

2. Explore the feasibility of expanding the recreational fishery in Guam into a major industry. Priority - high.

TRUST TERRITORY OF THE PACIFIC ISLANDS

Recognizing that the future political status of the Districts exclusive of the Northern Marianas has not been determined, I am including all of the Districts under the overall category of the Trust Territory for this section. Table 4 provides a summary of the ongoing fishery development activities in the Trust Territory area.

Aquaculture

Presently all of the aquaculture activities in the Trust Territory are being carried out at the Mariculture Laboratory located in Palau. Based on various sources, the Laboratory is reported to be working on a number of culture projects. Included are projects on the culture of mollies for possible baitfish use in the skipjack tuna pole-and-line fishery, culture of rabbitfish, and culture of several species of shellfishes and crustaceans

Inshore

There are no ongoing fishery development activities directed towards reef fishes.

Slopes and banks

Based on several reports, small-scale fishing on the pelagic resources of coastal waters is underway in Truk and Ponape.

Pelagic

A recent report from Ponape indicated that one of the five vessels obtained by the Government of the Trust Territory of the Pacific Islands from Japan as part of the reparation agreement is being successfully used in Ponape for skipjack tuna fishing. The vessel is under charter to a private concern which is reported to have foreign capital involved. PTDF is supporting a project in Truk to develop a small-scale fishery using a small multiple-purpose vessel. The plan is to carry out handline fishing for nearshore species and troll fishing for tunas.

NEW PROJECTS FOR FISHERY DEVELOPMENT

The following provides a list of potential projects for support in the Trust Territory:

Aquaculture

Nothing is proposed for the present.

Inshore

Nothing is proposed for fishery development in this area.

Slopes and banks

1. Expand efforts to help develop small-scale fishing in various parts of the Trust Territory. Efforts should be made to examine this propect on total systems approach and not piecemeal fashion. Priority - high.

Pelagic

1. Survey the deeper waters for baitfish resources. Determine the stock size of existing inshore baitfish resources. Priority - high.

2. Should the tuna aggregation work presently being conducted in Hawaii prove to be successful, efforts should be made to test this system in the western Pacific. Priority - high.

Table 1.--On-going Fishery Development Activities. Hawaii.

Activity	Level of activity	Agency				
		NMFS	"State"	Sea Grant	PIDC/PTDF	Industry
Aquaculture	high					
Baitfishes				x		
Finfishes			x			x
Shellfish/crustaceans			x	x		x
Others (algae)				x		
Inshore	low					
Reef fishes			x	x		
Slopes and banks	high					
Finfishes		x				
Crustaceans		x				
Pelagic	high					
Baitfishes						
Tunas and billfishes		x			x	
Others						

Table 2.--On-going Fishery Development Activity. American Samoa

Activity	Level of activity	Agency				
		NMFS	"State"	Sea Grant	PIDC/PTDF	Industry
Aquaculture						
Baitfishes	high		x	x(UH)	x	
Finfishes						
Shellfish/crustaceans						
Others						
Inshore	low					
Reef fishes						
Slopes and banks	high					
Finfishes			x			
Crustaceans						
Pelagics	low					
Baitfishes						
Tunas and billfishes						
Others						

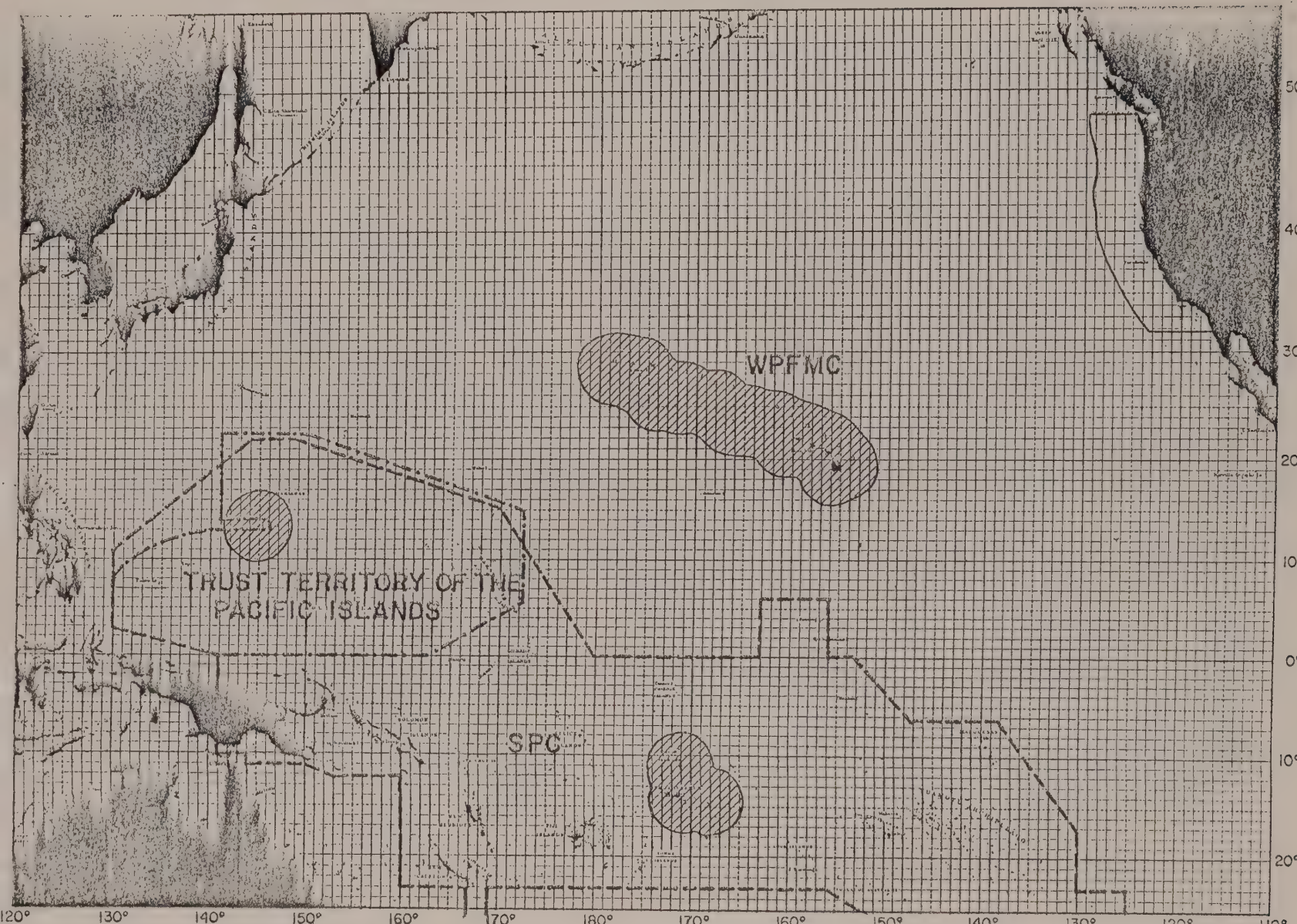
Table 3.--On-going Fishery Development Activities. Guam and Northern Marianas.

Activity	Level of activity	Agency				
		NMFS	"State"	Sea Grant	PIDC/PTDF	Industry
Aquaculture	high					
Baitfishes						
Finfishes						x
Shellfish/crustaceans						
Others						
Inshore	low					
Lagoons						
Reef fishes						
Slopes and banks	low					
Finfishes			x			
Crustaceans						
Pelagics	high					
Baitfishes						
Tunas and billfishes					x	
Others						

Table 4.--On-going Fishery Development Activities. Trust Territory.

Activity	Level of activity	Agency				
		NMFS	"State"	Sea Grant	PIDC/PTDF	Industry
quaculture	high					
Baitfishes			x (Palau)			
Finfishes			x (Palau)			
Shellfish/crustaceans			x (Palau)			
Others						
nshore	low					
Baitfishes						
lopes and banks	high					
Finfishes			x (Truk, Ponape)		x (Truk)	
Crustaceans						
elagics	high					
Baitfishes						
Tunas and billfishes			x (Ponape)		x (Truk)	
Others						

Territory of the Pacific Islands, and (c) South Pacific Commission.



1/ The shaded areas include the areas of overlapping jurisdiction between the USA and neighboring countries.

Southwest Fisheries Center Administrative Report No. 17H, 1977

DRAFT FOR COMMENT

FISHERIES ASPECTS OF CENTRAL AND WESTERN PACIFIC ISLANDS AREA

By

Richard S. Shomura 1/

NOV 9 1977

Author's notes

The following report summarizes my personal views and interpretations of present fisheries conditions in the central and western Pacific islands area, especially the South Pacific Commission area. The material is being summarized to provide U.S. Government and industry members with general fisheries information of the area. This may be useful as background material in participation of the fisheries policy meeting scheduled to be held in Suva, Fiji, in mid-November. This meeting is being called by the South Pacific Bureau for Economic Cooperation. Due to the press of time, I have not doublechecked some of the statements; however, I feel confident that the information is essentially correct.

INTRODUCTION

Since the recent move by countries to unilaterally impose an extended jurisdiction zone generally seaward to 200 miles, the island waters of the central and western Pacific have started to receive an upsurge in interest as it relates to marine fisheries. Interest in the U.S.A. and other distant-water fishing nations has been especially engendered by the scheduled meeting in Suva this month to discuss the organization of a South Pacific Fisheries Agency.

1/ Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, Hawaii 96812. November 1977.

GEOGRAPHY

The island areas of direct concern to the U.S.A. are shown in Figure 1 as the Western Pacific Fishery Management Council area. The WPFMC is one of the eight Councils created by the Fishery Management Conservation Act of 1976 and has responsibility for management of the fishery resources of the Hawaiian Islands, American Samoa, and Guam. The Northern Marianas will gain U.S.A. territorial status shortly, and is expected to fall under WPFMC. It should be noted that there are other islands in the central and western Pacific that the U.S.A. has some measure of responsibility. These include undisputed U.S.A. possessions, e.g., Johnston Island, condominiums, e.g., Canton Island, and a number of islands claimed by the U.S.A., but said claim being disputed by other countries, e.g., Christmas Island whose ownership is disputed by U.K.

Another major area of U.S. responsibility in the western Pacific is the Trust Territory of the Pacific Islands (Fig. 1). It should be noted that for the present the Northern Marianas is included in the TT area. Presently discussions are being carried by the Government of Micronesia to determine the ultimate political status of the remaining Districts that consitute the Trust Territory of the Pacific Islands. Finally, Figure 1 shows the area under jurisdiction by the South Pacific Commission.

GENERAL FISHERIES DEVELOPMENT

With respect to marine fisheries, there are basically two areas of concern; namely, (1) the lagoon and nearshore fishery resources and (2) the pelagic resources including the highly prized tunas. Except for some island areas, e.g., Indonesia, Philippines, and Papua New Guinea,

the lagoon and nearshore marine resources of most of the Pacific Islands are suspected to be relatively small in total biomass. Basically the resources are being used to meet domestic needs and only a small part is exported, e.g., spiny lobsters.

For the pelagic marine fishery resources, the island governments and territories of the SPC area until only recently were unable to participate in a meaningful manner with the development of the tuna resources of the region. Prior to World War II, Japan did some fishing for tunas using the longline gear in the western Pacific. Japan resumed tuna fishing in the equatorial waters of the western Pacific following termination of World War II. Subsequently, Japan rapidly expanded her tuna fishing capabilities and extended fishing operations throughout the tropical and subtropical waters of the world's oceans for tunas. Fishing with longline gear was focused primarily on the yellowfin tuna (Thunnus albacares), bigeye tuna (Thunnus obesus), and albacore (Thunnus alalunga).

Until recent years the fishing for skipjack tuna (Katsuwonus pelamis) in the central and western Pacific was confined to coastal waters off Japan and around a few other island areas, e.g., Hawaii, Ryukyu Islands, and Palau. About 10 years ago Japan began utilizing far-ranging pole-and-line vessels to fish for skipjack tuna throughout the tropical and southern waters of the Pacific. The success of Japan's extensive southern water fleet operations is reflected in the increased Pacific catch of skipjack tuna. From a previous pre-World War II annual average catch of around 100,000 metric tons, Japan has increased its skipjack tuna catch

markedly. Presently Japan's annual landings are in the neighborhood of 400,000 MT. It should be noted that in recent years other countries have become interested in the skipjack resources of the central and western Pacific; namely, United States, U.S.S.R., and the various island governments and territories of the area.

Almost without exception the island nations and territories of the central and western Pacific are looking towards the tuna resources as being the only marine fishery resources capable of providing economic benefits to the island communities. As noted earlier the insular resources of these island areas are not considered to be extensive and definitely not in the same economic class as the tunas. As a result, the island governments are looking towards economic returns via licensing, joint ventures or direct participation in the tuna fisheries.

ORGANIZATIONS

The following provides a brief review of the several organizations which concern themselves with fishery matters in the central and western Pacific area.

INDO-PACIFIC FISHERIES COMMISSION (IPFC)

The IPFC is an international fisheries body sponsored by FAO to provide a forum whereby member nations are able to discuss fisheries problems of mutual interest. In recent years the IPFC has made overtures to move from an advisory body to one which is more action-oriented; recent activities are for more direct involvement in programmatic areas and in fisheries management. The present membership of IPFC consists of 18 nations (Australia, Bangladesh, Burma, Democratic Kampuchea, France,

India, Indonesia, Japan, Republic of Korea, Malaysia, New Zealand, Pakistan, Philippines, Sri Lanka, Thailand, United Kingdom, U.S.A., Vietnam). While membership is open to all countries affiliated with the United Nations, none of the independent island nations located within the South Pacific Commission area is a member of IPFC. After Fiji achieved independence in 1970, it expressed interest in joining IPFC in 1972; however, at the last minute, Fiji withdrew its plans for membership. Based on unofficial views, the general comment expressed has been that island nations of the South Pacific Commission area were not interested in joining IPFC primarily because IPFC appeared to be a body interested in fisheries matters of Southeast Asia and the Indian Ocean and that fishery matters of the island community were given low priority. Furthermore, the fisheries needs of the South Pacific islands area appeared to be met to some extent by the South Pacific Commission.

Geographically, the areas of concern to IPFC have not been defined. This was done deliberately to provide flexibility. Generally the fisheries matters under consideration by IPFC at its biennial meetings have extended as far east to cover the fisheries of Hawaii and as far west to cover the fisheries of India and Sri Lanka. It should be noted that with the creation of the Indian Ocean Fisheries Commission (IOFC) the IPFC has deliberately reduced emphasis in the Indian Ocean and presently concerns itself with marine fisheries matters of the western Pacific and Southeast Asia and the inland fisheries aspects of the entire membership area.

SOUTH PACIFIC COMMISSION

The Commission was organized in 1947 by six metropolitan governments having territories with direct interest in the South Pacific islands area. These countries included Australia, France, Netherlands, New Zealand, United Kingdom, and the United States of America. The Netherlands withdrew membership in 1962. As the island governments gained independence, they joined the Commission. Western Samoa joined in 1964, Nauru in 1969, Fiji in 1971, and Papua New Guinea in 1975. The area of Commission concern is shown in Figure 1. It should be noted here that while the Commission is called South Pacific Commission, the area circumscribed by the Commission includes a substantial group of islands located to the north of the equator, i.e., the Trust Territory of the Pacific Islands and the Line Islands chain. It should also be noted that islands not included in the Commission area include the State of Hawaii, Philippines, and Indonesia.

The Commission undertakes a wide range of activities and the prime purpose is to advise the participating governments on ways to improve the well being of the peoples of the area. The activities sponsored by the Commission range into fields of food and material, marine resources, world management and technology, community services, information services, and data analysis. In essence it appears that the Commission is a mini-FAO organization. The Commission's headquarters are located in Noumea, New Caledonia. The Commission originally met annually in Sessions. The present Secretary-General of the Commission is Dr. Macu Salato of Fiji.

THE SOUTH PACIFIC CONFERENCE

The South Pacific Conference was formed in 1950 when it held its first meeting. The South Pacific Conference was originally a meeting of delegates from countries and territories within the Commission area. The meetings of the Conference were held just prior to the Commission Sessions. Sometime during the early 1970's the membership of the Commission and the South Pacific Conference got together and decided to hold joint meetings. These joint meetings were also to be called the South Pacific Conference. Thus, the first joint Conference was held in October 1974.

While not confirmed, the U.S.A. participation in the Conference consists of (1) a U.S.A. delegation headed by the U.S.A. Commissioner, (2) a delegation from American Samoa, (3) a delegation from Guam, and (4) a delegation from the Trust Territory of the Pacific Islands.

THE SOUTH PACIFIC FORUM

During the course of attending South Pacific Conference meetings a number of island governments became disenchanted with the constraints imposed by the Conference. Delegates of these countries felt that it was impossible to discuss political matters at the South Pacific Conference; thus, they took to meeting on an ad hoc basis outside of the Conference. Another unofficial reason for organizing the Forum was that the island governments felt that the developed countries tended to overwhelm them at the Conference.

As a result, these island governments organized themselves into a group known as the South Pacific Forum. The Forum met officially for the first time in August 1971. The current membership consists of Nauru, Fiji,

Australia, New Zealand, Papua New Guinea, Cook Islands, Niue, Western Samoa, and Tonga. What sets the Forum from other official bodies is that the Forum is a meeting of officials at the prime ministerial level.

At the meetings of these prime ministers the discussion centers around setting of policies on matters of mutual interest. Implementation of many of the policy matters is delegated to an organization called the South Pacific Bureau of Economic Cooperation (SPEC). The Forum last met in Papua New Guinea in August 1977.

Some of the problems faced by the South Pacific Commission and the South Pacific Forum are detailed in an account (Attachment A) by John Carter, who described activities at the 17th South Pacific Conference held in Pago Pago, American Samoa in September 1977.

SOUTH PACIFIC BUREAU FOR ECONOMIC COOPERATION (SPEC)

This organization was established in 1972 with funds provided by Australia and New Zealand. While its activities probably are wide-ranging, for the purpose of the present discussion SPEC operates as a "Secretariat" for the South Pacific Forum. Basically their efforts to date have been to develop free trade among its membership. The present Director of SPEC is Mr. Mahe Tupouniua.

SOUTH PACIFIC FISHERIES AGENCY

At a Forum meeting held in Suva, Fiji, in October 1976, the Forum directed SPEC to prepare proposals for the establishment and operation of a South Pacific Fisheries Agency. A draft document (Attachment B) was prepared in May 1977 by SPEC with the assistance of specialists from the South Pacific

Commission and the Fisheries Division of the Australian Department of Primary Industry. Subsequently, a working group consisting of experts from the South Pacific Commission, Government of Australia, and representatives from several Forum countries met in Suva, Fiji, in July 1977 to review and revise the draft document. The revised document was completed and submitted at the Forum meeting held in Port Moresby, Papua New Guinea, on 29-31 August 1977. Attachment C provides the report of the Director of SPEC to the Forum entitled "Establishment of a South Pacific Fisheries Agency." The Forum then presented its views on the Law of the Sea and the need for a regional fisheries agency and requested the Director of SPEC to convene a meeting of officials of all interested coastal states in the region to (1) prepare a draft convention establishing a South Pacific regional fisheries body, (2) arrange for an interim agency office, and (3) discuss and prepare guidelines for the agency. Attachment D entitled "Declaration on Law of the Sea and a Regional Fisheries Agency" provides the report in full.

PRESENT FISHERIES ACTIVITIES

In general the various island governments and territories in the region carry out very little fisheries research and development work. Some details are provided in a later section; the present section highlights the international fisheries activities.

SOUTH PACIFIC COMMISSION

The Commission's fisheries work is carried out by a Fisheries Adviser whose office is in Commission headquarters in Noumea, New Caledonia.

Mr. Rene Grandperrin, a fishery biologist, who was formerly with ORSTOM (a French overseas fisheries organization) in Noumea, assumed the post of Fisheries Adviser in mid-1976. The fisheries work is basically a one-man operation. The Fishery Adviser's functions are to (1) provide fisheries advice to the Commission, (2) prepare proposals for Commission support, (3) provide advice and coordination among fisheries officers of the region, (4) overview Commission-sponsored fisheries projects, and (5) disseminate fisheries information to the fisheries officers of the region, and (6) organize and run the regional technical fisheries meetings.

COMMISSION'S REGIONAL TECHNICAL MEETINGS ON FISHERIES

The Commission sponsors an annual meeting of the Fisheries Officers of the Commission area. The last (Ninth) meeting was held in Noumea, New Caledonia, on January 24-28, 1977. Basically, the meeting provides an opportunity for the Fisheries Officers to review their activities, exchange information, and review the Commission-sponsored projects.

COOPERATIVE SKIPJACK TAGGING PROGRAMME

Recently the Commission became involved in a cooperative skipjack tagging program. The objectives of the tagging program are to determine the migratory pathways of skipjack tuna in the central and western Pacific, aid in stock identity, and obtain some ideas of the population size of skipjack tuna in the area. Additionally, the program is planned to provide island areas with an opportunity to obtain information about their baitfish resources and to become exposed to the pole-and-line technique of tuna fishing. The present program commenced field work in October 1977 and is expected to run for three years. The countries funding this project

to date include Australia, New Zealand, and the U.S.A. Japan has contributed to this program, thus far, by donating three months of vessel time to get the program started. The program is presently headed by Dr. Robert Kearney, who is on the staff of the Commission.

UNDP REGIONAL FISHERIES COORDINATOR

The UNDP has Mr. Harry Sperling as the Fisheries Coordinator for the region. He is presently based in Suva, Fiji. Mr. Sperling's responsibilities are primarily to assist island governments in reviewing their fisheries needs and to assist in preparing proposals for UNDP support. As an example, he recently toured the Trust Territory of the Pacific Islands and helped prepare a fisheries development package.

OVERVIEW OF COUNTRIES AND TERRITORIES OF THE SOUTH PACIFIC COMMISSION AREA

The following provides a very brief country-by-country status report as it relates to fisheries matters.

AUSTRALIA

Status

Independent nation. Australia's primary role in the South Pacific Commission is as a donor country. I believe Australia is a major contributor to the finances that operate the Commission.

General fisheries comments

Australia plans to move in concert with the other island governments on matters relating to extended jurisdiction. With regard to tuna fisheries, Australia presently has an ongoing fishery for southern bluefin (Thunnus maccoyii) by pole-and-line and purse seine methods. Skipjack tuna are

taken in varying quantities; however, a major viable fishery for this species has not been established to date.

Fisheries research and management

The federal fisheries matters are handled by CSIRO.

NEW ZEALAND

Status

Independent nation.

General fisheries comment

With regard to tuna fishing, New Zealand has a small surface albacore fishery. For various economic and technical reasons, the fishery has not expanded; however, the resource base appears to be large enough for a substantial expansion of this fishery. The skipjack fishery had its start only 3-4 years ago and has shown a remarkable success. The catch has steadily increased and is now around 5,000-10,000 tons. The fishery is presently being operated by an arrangement involving the New Zealand Government, New Zealand fishing industry, and U.S. tuna fishing interests. The fishery is based on capture by the purse seine method.

Fisheries research and management

Research is handled by a fisheries group headed by Mr. G. Duncan Waugh. While small in size the staff is rated high in technical competence. The management area is handled by Mr. Brian Cunningham.

PAPUA NEW GUINEA

Status

Gained independence on September 16, 1975.

General fisheries comments

PNG is reported to have considerable fisheries resources which are still underutilized. Outside of Japan, the fishery for skipjack tuna in Papua New Guinea showed the most marked success. In 1974 the skipjack catch amounted to 40,000 metric tons. Skipjack fishing is carried out by joint venture arrangements involving the Government of PNG and private Japanese and U.S. interests. It is reported that the Government of Papua New Guinea has not been overly satisfied with the joint venture arrangements with the Japanese companies. One of the two Japanese companies is reported to have ceased operation in Papua New Guinea.

Fisheries research and management

Peter Wilson, a former resident of Hawaii, is currently attached to the Government of Papua New Guinea by UNDP as a Fisheries Adviser. My understanding is that Mr. Wilson has reviewed the total fisheries arena of PNG and is providing the Government with advice on a wide range of fisheries topics, e.g., fisheries development, research and management. He is presently recruiting for some senior scientists to fill positions in the research unit.

SOLOMONS

Status

Protectorated under U.K.; expected to gain independence soon.

General fisheries comments

Is a transshipment base for foreign longline vessels. Has a joint venture arrangement with Japanese fishing concerns to develop the skipjack fishery of the Solomons area. I believe the recent skipjack catch for the Solomons has been between 10,000 to 20,000 metric tons.

The Solomons has been selected as the permanent headquarters for the projected South Pacific Fisheries Agency.

Fisheries research and management

A Mr. Richard James of the U.K. is presently the Principal Fisheries Officer for the Solomons. Mr. James is a young, knowledgeable individual who has had some commercial fishing experience in England. He is aggressive and not reluctant to make the views of Solomons' interest known at fisheries meetings. This is done firmly but politely.

COOK ISLANDS

Status

Gained internal self-government status under New Zealand in 1965.

General fisheries comments

The Cook Islands have been interested in developing their fisheries for some time. Several years ago the Cook Islands was involved in an aquaculture project to rear lobsters; the project failed miserably. While the Cook Islands are undoubtedly interested in developing a skipjack fishery, it is uncertain as to what the availability and abundance of skipjack is in Cook Islands waters. Also, the perennial problem of baitfish exists.

Fisheries research and management

The Principal Fisheries Officer for the Cook Islands is a Mr. Thomas Marsters. Sir Henry, who is the Prime Minister for the Cook Islands, has a keen interest in fisheries and has expressed the Cook Islands' views eloquently in the past. He has expressed willingness to negotiate with U.S.S.R. if it will help the Cook Islands.

FIJI

Status

Gained independence on October 10, 1970.

General fisheries matters

In past years Fiji made some attempts to develop an aquaculture industry. Species examined included oysters and tilapia. I believe effort in aquaculture development is presently at a low level or dormant. With regard to nearshore fisheries, the present Fijian administration is encouraging the development of fisheries for nearshore and slope resources, e.g., snappers and groupers. For tuna fishing, Suva is a transshipment base for a foreign longline fishing fleet. The Fijian Government entered into a joint venture arrangement with a Japanese firm recently to develop a skipjack fishery. Presently the joint venture operates a small tuna cannery in Suva. Albacore caught and landed by the longline fishery is being canned and exported to the U.S.A. The skipjack catch is being canned and the entire catch is reported to be consumed locally. The skipjack fishery is in its initial stages of development, and the fishery is based on catches made by several chartered Japanese pole-and-line vessels. The present annual catch is estimated to be in the neighborhood of 1,000-2,000 tons. From all accounts the potential for growth of the skipjack fishery is good. The baitfish supply appears more than adequate to support a small fishery.

Fishery research and management

Mr. Robert Stone is the Principal Fisheries Officer for the Government of Fiji. He is a native Fijian who spent two years (1973-75) at the

Fisheries School of the University of Rhode Island. Mr. Stone is a young, aggressive, and level-headed individual who thinks in practical terms as it relates to fishery development.

It should be noted here that Mr. Stone, Mr. Henry Sesepasara of American Samoa, and Mr. Marsters of the Cook Islands are probably the only fisheries officers who are native-born and citizens of their island governments or territories. All others are expatriates.

NEW CALEDONIA

Status

Overseas territory under France.

General fisheries comments

Fishing is completely on an artisanal basis at the present time. Not much is known about the marine resources available in New Caledonia. With regard to tunas, the French administration has expressed interest with the development of a tuna fishery; however, no substantive field work has been undertaken to date. Much of the emphasis in fishery work has been undertaken to date. Much of the emphasis in fishery work has been in the aquaculture area. There is an aquaculture station in Noumea where research is focused on the culture of penaeid shrimp.

Fisheries research and management

Mr. Jean Claude LeGuen is the Principal Fisheries Officer for the French Government in New Caledonia. I believe he heads the ORSTOM organization based in Noumea, New Caledonia. My understanding is that the French Government plans to expand fisheries research in the Pacific island area. Mr. LeGuen is presently developing plans to expand their research on skipjack tuna.

WESTERN SAMOA

Status

Gained independence on January 1, 1962.

General fisheries comments

Although the islands that make up Western Samoa are larger than the islands making up American Samoa, the problems in fisheries are essentially the same. Fishing is presently confined to nearshore artisanal fishing. With regard to skipjack, the UNDP has a project which hopes to develop the skipjack fishery. Efforts appear to be below critical mass. Western Samoa has a problem of inadequate baitfish supply and is therefore engaged in a mollie culture experiment similar to that operated in American Samoa. Additionally, UNDP has a project to assist the Western Samoan people in upgrading their small-boat fishing capabilities. There have been reports of recent U.S.S.R. and Republic of China interest shown in Western Samoa.

Fisheries research and management

I do not believe the Western Samoan Government has on its staff any fisheries expertise. Fisheries assistance is provided by international organizations such as UNDP.

FRENCH POLYNESIA

Status

Overseas territory under France.

General fisheries comments

There is some development of the nearshore fishery resources in French Polynesia. I understand some fish are being taken in Tuamotus and

shipped to Tahiti markets. There is a small pole-and-line skipjack fishery based in Papeete, Tahiti, which utilizes the Polynesian style of fishing. I believe the annual catch is in the neighborhood of 2,000 tons per year. Large skipjack exceeding 30 pounds are not uncommon in the Papeete fish markets. Presently the French Government is making an effort to further develop the skipjack fishery. I understand a small pole-and-line vessel has been purchased and is now operating in the Marquesas area.

Fisheries research and management

The French Government has a CNEXO unit in French Polynesia which operates a sizable aquaculture plant in Vairao, Tahiti. A wide range of species is being evaluated; emphasis is on penaeid shrimp. The Inter-American Tropical Tuna Commission is presently engaged with the French Government on a cooperative skipjack tagging project. Tagging is presently going on in the Marquesas area.

The local Tahitian Government has a small fisheries unit which is equivalent in concept to a State Fish and Game entity. Based on very limited contact it appears that the local fisheries unit and the CNEXO group are not on the best operating terms.

TUVALU

Status

Gained independence on October 1, 1975. Formerly the Ellice Islands of the Gilbert and Ellice Islands Group.

General fisheries comments

Tuvalu consists of a series of islands which have very narrow fringing reefs. Because of the very limited lagoon and reef area, the inshore

fishery resources are considered to be very small. The Government of Tuvalu hopes to expand its fishery activities utilizing small vessels. Also, the Government is interested in developing its tuna resources; however, it is not quite sure what is available and what the best approach should be toward its development. Based on very scanty data, there appears to be very little baitfish in the area.

Fisheries research and management

Tuvalu does not have anyone with substantial fisheries background.

GILBERT ISLANDS

Status

Self-government status under United Kingdom. I believe the Gilbert Islands is expected to gain independence in the near future.

General fisheries comments

The situation in the Gilberts is very similar to Tuvalu. Presently there is a UNDP project to develop a skipjack fishery in the Gilberts. Since baitfish are lacking in the area the project is working on the suitability of culturing sufficient quantities of young milkfish. The lagoon in Tarawa has been modified to create a number of earthen ponds. Milkfish fry are taken from wild stocks and placed into the ponds. Information is not available on the present status of this project; however, it has been reported that the milkfish will be tried next year on an SPC-sponsored skipjack tagging vessel.

Fisheries research and management

A Mr. Hollness is presently the Fisheries Officer for the Gilbert Islands.

I believe he is a staff member of the United Kingdom's overseas unit on loan to the Gilberts. Mr. Hollness was formerly with the PNG fisheries group.

TRUST TERRITORY OF THE PACIFIC ISLANDS

Status

The Northern Marianas District will gain territorial status next year. The other Districts making up the Trust Territory of the Pacific Islands are presently in the process of determining their future political destiny.

General fisheries comments

For most of the areas where relatively large population centers exist the nearshore fishery and lagoon resources have been reported to be heavily fished. It is generally believed the slope and bank resources of the various parts of the Trust Territory hold sufficient fishery resources for expansion of coastal fisheries. The magnitude of the resources are probably not large enough for a substantial export market. Considering the Trust Territory area as a whole, it is probably the center of tuna fishing activity in the western Pacific. There is extensive longline and pole-and-line fishery in this area. After World War II the Japanese longline fleet centered its operation in the Trust Territory area and caught substantial quantities of yellowfin and bigeye tuna. It is believed that a substantial longline fishery still operates in the Trust Territory region.

While a detailed examination of the time and space distribution of the Japanese southern pole-and-line fishery fleet has not been undertaken,

it is believed that a substantial part of the Japanese southern tuna fleet operates in the Trust Territory area. One can assume that a large share of the 200,000 metric tons of skipjack tuna taken in the western Pacific by the Japanese southern fleet is taken in the TT area. Other tuna fishing activities in the area include a small U.S.A.-operated pole-and-line fishery based in Palau. The fishery lands from 5,000 to 10,000 metric tons a year and utilizes the Japanese type pole-and-line vessels. The catch is transshipped to U.S.A. canneries. A recent study of the baitfish resources in the area concluded that the baitfish supply is adequate for sustaining a small fleet.

One of the small pole-and-line vessels obtained by the Trust Territory Government from Japan as part of the reparation agreement is being utilized at Ponape for surface tuna fishing. My understanding is that the vessel is on charter to a private firm and is having some measure of success in catching skipjack tuna using the pole-and-line technique. The other reparation vessels are reported to be lying idle in Palau.

AMERICAN SAMOA

Status

Territory of the U.S.A.

General fisheries matters

In all probability the nearshore and lagoon fishery resources of American Samoa are being fully utilized. Presently a small dory fishery operates on the slope and bank waters of American Samoa; catches are primarily made up of snappers and groupers. One of the major problems faced by this fishery has been the necessity to discard about 50 percent of the

catch because it is made up of the red snapper (Lutjanus bohar) which has the reputation of being highly toxic.

The Government of American Samoa, in cooperation with NMFS and the Pacific Tuna Development Foundation, is presently engaged in rearing Mexican mollies to be tried as baitfish for pole-and-line tuna fishing. Present plans are to conduct field trials early 1978.

Presently the major fishery in American Samoa is a foreign-operated longline fishing fleet which based out of Tutuila, American Samoa. The catch is processed by two U.S.A. canneries located in Pago Pago. In recent years the longline landings in American Samoa, as well as landings made in other parts of the central Pacific, have declined. The decline has been due to several causes, including reduced fishing effort due to the sharp increase in oil prices in 1975.

Fishery research and management

The Principal Fisheries Officer is Mr. Henry Sesepasara, a native of American Samoa. A substantial part of the operation of the fisheries activity in American Samoa is funded by the U.S. 88-309 Program.

TONGA

Status

Gained independence on June 4, 1970.

General fisheries comments

The Government operates a longline vessel which sells the catch through local markets. While the operation is not believed to be self-sustaining the consumption of fish in Tonga has probably increased substantially. The crew of the longline vessel is made up predominantly of Tongans.

The Government of Japan has a "Peace Corps"-type fishery project in Tonga. I believe the original plan was to aid in the development of a surface tuna fishery. The project has not gotten off the ground, primarily due to the lack of baitfish. It does not appear that this project represents a sincere effort, since the project is considerably undermanned, e.g., availability of only one technical specialist.

The UNDP recently initiated a project to develop skipjack fishing. How this ties in with the Japanese effort is not known. The UNDP project has located some baitfish in the northern islands. The fishing trials are projected for the next phase of this project.

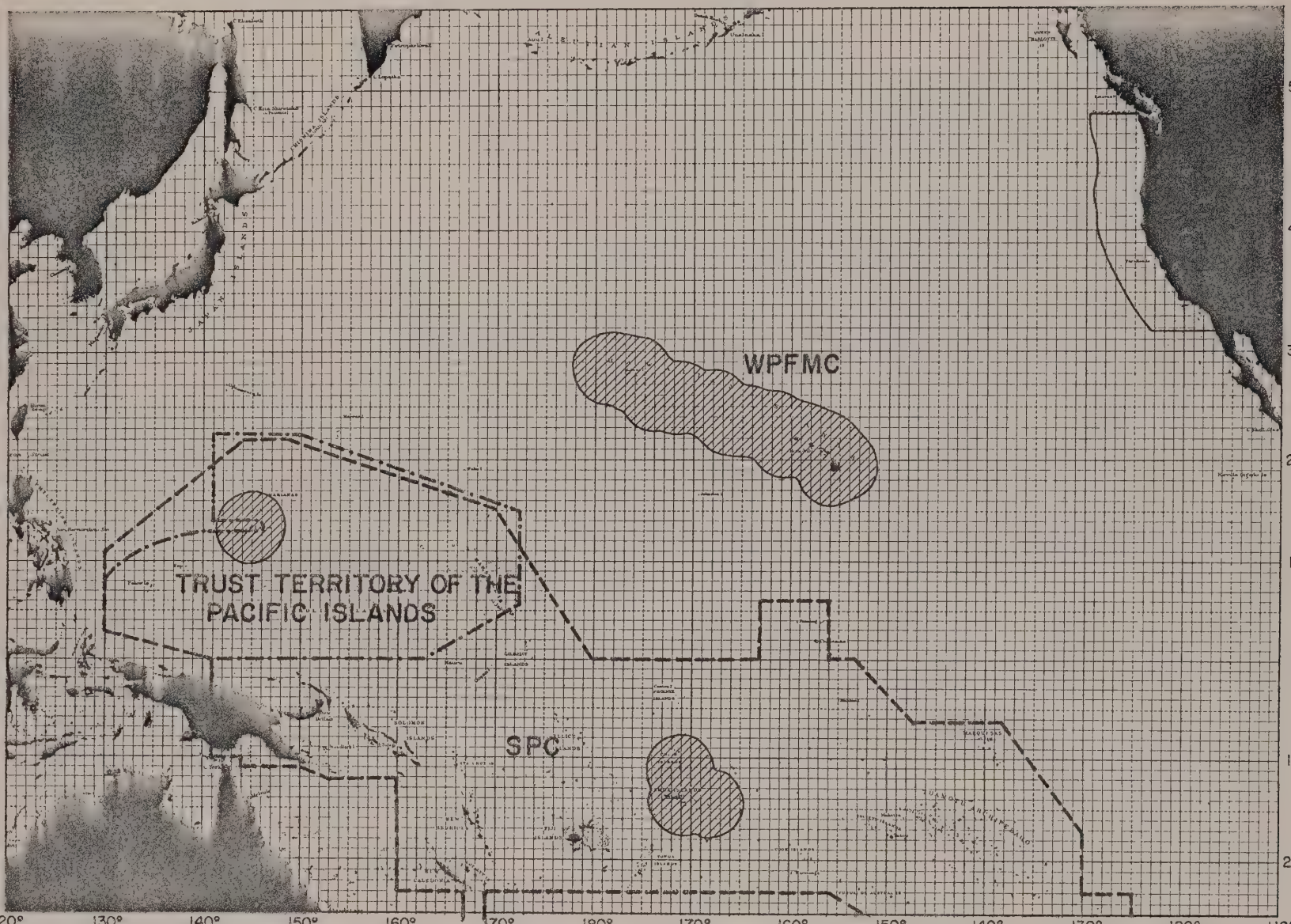
Fisheries research and management

The Principal Fisheries Officer is a Mr. William Wilkinson. Like all of the other fisheries officers in the Commission area, Mr. Wilkinson operates a fishery unit which is grossly understaffed and underfunded.

OTHERS

Due to the press of time and the general lack of information, summary reviews are not provided for Guam, New Hebrides, Niue, Tokelau Islands, and the Wallis and Futuna Islands.

Territory of the Pacific Islands, and (c) South Pacific Commission.



1/ The shaded areas include the areas of overlapping jurisdiction between the USA and neighboring countries.

Southwest Fisheries Center Administrative Report No. 18H, 1977

AN ASSESSMENT OF PACIFIC BILLFISH STOCKS BASED ON THE GENERALIZED PRODUCTION MODEL

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This is a draft working paper prepared solely for discussions at the Pacific Billfish Stock Assessment Workshop. It is not intended for publication in its present form and should not be cited.

INTRODUCTION

The purpose of this paper is to present results of a preliminary assessment of Pacific billfish stocks. Attention is focused primarily on blue marlin, Makaira nigricans, and striped marlin, Tetrapturus audax, but black marlin, M. indica, swordfish, Xiphias gladius, and sailfish-spearfish, Istiophorus platypterus and T. angustirostris combined, are also treated.

The assessments are based on a standard production model analysis of Japanese tuna longline data, and the status of each assumed stock is measured in terms of the usual criteria of maximum sustainable yield (MSY) and the associated "optimum" fishing effort (E_{opt}). The analysis rests on some assumptions which may be untenable. We do not study these in detail here; they will be examined in depth in another paper.

The basic procedure followed was to (1) adopt stock boundaries, (2) compute an index of abundance for each stock, and a measure of effective fishing effort, and (3) estimate the MSY and E_{opt} parameters of the production model using computer programs. The following sections outline the data sources, describe the assumed stock boundaries, and discuss the abundance indices. Finally, the production model results are presented and evaluated.

DATA SOURCES

Data on number of billfish caught and nominal effort (hooks fished) by month and 5° square were taken from published statistics of the Japanese tuna longline fishery for the years 1962-75. These

were augmented by unpublished Japanese data for the period 1952-61 provided by the Far Seas Fisheries Research Laboratory. Tuna longline catch and effort statistics by month and 5° square were also available for the Chinese fishery for 1967-74 and for the Korean fishery over the period 1966-70. Information on total weight of Pacific billfish catch and/or landings was extracted from FAO yearbooks of fishery statistics for the 1952-75 period.

To ensure consistency and completeness indices of abundance were based solely on Japanese longline statistics. However, total catch figures were estimated on the basis of raising factors computed either from Chinese and Korean longline data or the FAO statistics.

In the FAO data tables, estimates of billfish catches in metric tons are given for each ocean from 1964 through 1975, but figures for earlier years are not separated by ocean. Estimates of Pacific billfish catches prior to 1964 were derived using appropriate adjustment factors computed from more recent data. Even though Japanese catches dominate the FAO statistics, separate adjustment factors were applied to the Japanese data and the catch histories for all countries combined. Additional corrections were necessary in the case of blue and black marlin, for which catch data were combined in the earlier years. Again, adjustments were made to these data based on the known species composition of recent catches.

STOCK BOUNDARIES

For purposes of computing indices of abundance, several index areas were selected (Figure 1):

1. Total Pacific

   Lat. 40°S-40°N

   Long. 120°E-80°W

2. North Pacific

   Lat. 20°-45°N

   Long. 120°E-130°W

3. Central Pacific

   Lat. 10°S-20°N

   Long. 120°E-130°W

4. South Pacific

   Lat. 10°-35°S

   Long. 140°E-130°W

5. Eastern Pacific

   Lat. 30°S-35°N

   Long. 70°-130°W

6. Southwest Pacific

   Lat. 0°-50°S

   Long. 120°E-180°

The North, South, and eastern Pacific areas are assumed to encompass the distributions of three hypothesized striped marlin stocks, although a Pacific-wide stock is also considered. The central Pacific area is used in indexing the abundance of blue marlin, and the southwest area is used for black marlin. Swordfish and sailfish-spearfish are examined on a Pacific-wide basis.

INDICES OF ABUNDANCE

Two kinds of annual abundance indices were developed, each computed from Japanese statistics of catch and nominal effort by quarter and 5° square. The first was a simple average of ratios catch per unit of effort statistic:

$$U_{1i} = \sum_{j=1}^{n_i} (C_{ij} / f_{ij}) \Big/ n_i$$

where U_{1i} = average of ratios index of abundance for a particular species in year i (fish per 10^3 hooks)

C_{ij} = catch of the given species in time-area stratum j during year i, within a specified index area (10^3 fish)

f_{ij} = corresponding nominal effort in stratum j during year i (10^6 hooks)

n_i = number of quarter x 5° square strata in year i with non-zero effort.

This index may be satisfactory in situations where the time-area distribution of fishing effort is reasonably complete, e.g., in subareas of the Pacific. However, when the area considered is large, the index is apt to be biased as a result of incomplete coverage during years of fleet expansion or contraction. An alternate index of abundance which is corrected to some degree for incomplete coverage is based on the effective fishing intensity of Honma (1974):

$$U_{2i} = \sum_{j=1}^{\ell_i} C_{ij} \Big/ \sum_{j=1}^{\ell_i} f_{ij}\varepsilon_{ij}$$

where the new symbols are

U_{2i} = corrected index of abundance for a particular species in year i

ε_{ij} = relative efficiency of a unit of nominal effort in stratum j during year i for the particular species, equal to the average abundance in the j-th stratum divided by the average abundance over all strata

ℓ_i = number of time-area strata in year i with both non-zero effort and $m_j \geq 3$ (see following explanation).

When ℓ_i is equal to the total number of time-area strata covering the stock distribution, U_{2i} reduces to an unbiased average of ratios index of abundance. [Note that the effective fishing intensity is $f'_{i.} = \Sigma f_{ij}\varepsilon_{ij} = I_i \Sigma f_{ij}$, where I_i is the concentration coefficient and the summation is over all time-area strata. In other words, the concentration coefficient is a weighted average of Honma's relative efficiencies, with the weights equal to the nominal efforts.]

Honma's idea is to replace ε_{ij} by an estimate, $\hat{\varepsilon}_{ij} = \varepsilon_j$, based on data from years with nearly complete geographical-temporal coverage. He uses the estimator

$$\varepsilon'_j = d_j \Big/ (\Sigma d_j A_j / \Sigma A_j)$$

where $d_j = \sum_{k=1}^{m_j} (C_{kj} / f_{kj}) \Big/ m_j$

m_j = number of years when the j-th time-area stratum was fished

A_j = relative area of the geographical stratum associated with time-area stratum j

k = year index for j-th stratum ($k = 1, 2, \ldots, m_j$).

Instead of Honma's statistic, we used

$$\varepsilon_j = \sum_{k=1}^{m_j} \left\{ g_{kj} \Big/ \left[\sum_{j=1}^{\ell_k} g_{kj} A_j \Big/ \sum_{j=1}^{\ell_k} A_j \right] \right\} \Big/ m_j$$

where $g_{kj} = C_{kj} / f_{kj}$.

Essentially, Honma's estimator is a ratio of averages, whereas ours is an average of ratios.

In practice, when computing U_{2i} we sum the catches and adjusted efforts only over those time-area strata having both non-zero effort in the index year and at least 3 years of non-zero effort during the period over which the ε_j are estimated.

Figure 2 shows the relative time-space coverage of the Japanese tuna longline fleet in the different index areas over the 1952-75 period. The statistic plotted is the ratio of the number of quarter-5° square strata in which fishing occurred to the maximum number of strata covered during one of the 24 years. In estimating the ε_j we used Japanese longline statistics from the 1964-70 period, when coverage was the most complete.

EFFECTIVE EFFORT

Effective effort was computed by dividing the total annual catch of the species under consideration (raised to include the take of all harvesters) by the appropriate index of abundance, i.e.,

$$E_{1i} = C_{i.} / U_{1i}$$

$$E_{2i} = C_{i.} / U_{2i}$$

TRENDS IN ABUNDANCE AND EFFECTIVE EFFORT

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1

The indices of abundance and effective effort are plotted in Figures 3 through 14 and are listed in Tables 1 through 11. Two sets of indices are shown for blue marlin; the U_1 index for the central Pacific area (Figure 3) and the U_2 index for the total Pacific (Figure 4). Both indices depict a steady decline in blue marlin abundance since the inception of the Japanese pelagic longline fishery, with the 1975 stock size perhaps only 10%-20% of the 1952 stock level. Effective effort has increased fourfold or fivefold over the period.

The striped marlin index for the North Pacific area, of type U_1, shows marked fluctuations, but a generally increasing trend from 1952-71, followed by a sharp drop in the 1972-75 period (Figure 5). The corresponding effort index shows a declining tendency through the mid-1960's, followed by an increasing pattern through 1974. The U_1 index for striped marlin in the South Pacific (Figure 6) shows a sixfold decline from the early 1950's through 1967, followed by an increase in abundance in more recent years. The effective effort index, E_1, increased erratically through the mid-1960's, and has shown a fourfold or fivefold decrease since then. The eastern Pacific striped marlin index, U_1, was low until the Japanese longline fleet began to concentrate on this species in the early 1960's off Mexico and Central America (Figure 7). The abundance index then quadrupled, along with effective effort. Since then both indices have shown marked fluctuation around a fairly steady level, except that U_1 dropped to a low level in 1973-75.

The striped marlin indices in the North Pacific and eastern Pacific areas are not particularly clear in revealing expected relationships between average abundance and effective fishing effort. If separate striped marlin stocks exist in the three subareas, then only in the South Pacific would it seem possible to judge the effect of fishing on abundance using simple production model analysis. However, if we assume a single Pacific-wide stock, a more distinct pattern is seen. Figure 8 shows the U_2 and E_2 indices for striped marlin over the whole Pacific. A 2.5-fold reduction in striped marlin abundance is evident since the early 1950's, associated with a fivefold or sixfold expansion of effective fishing effort.

The U_2 and E_2 indices for the combined sailfish-spearfish group are shown in Figure 9. These were computed from Pacific-wide data, and show a reduction in average abundance over 1952-75 to half the original level, associated with an effective effort which increased steadily through 1968 and has decreased somewhat since. In Figure 10 we plotted the U_1 and E_1 indices for sailfish-spearfish in the eastern Pacific index area. The patterns are similar to the ones for striped marlin in that area.

Two sets of indices were computed for black marlin; U_1 and E_1 for the southwest Pacific index area, and U_2 and E_2 for the whole Pacific. The average of ratios catch per unit effort index, U_1, declined steadily from 1954 through 1975 (Figure 11). The associated effective effort increased erratically through 1966, but has fallen off in more recent years. The U_2 and E_2 indices show similar patterns; a fourfold to fivefold reduction in average abundance of black marlin

Pacific-wide, accompanied by an effective effort which increased through the mid-1960's and has been relatively constant since (Figure 12).

Figure 13 shows the U_2 and E_2 indices for broadbill swordfish, Pacific-wide. The abundance index increased from 1952 to 1958, then declined until 1964, and has been relatively steady since. Effective effort has been very erratic, but has had a basically increasing trend, at least up through 1970.

PRODUCTION MODEL ANALYSIS

The general production model was fitted to indices of abundance and to smoothed indices of effective effort using Fox's PRODFIT program (Fox 1975). For blue marlin, black marlin, striped marlin, and broadbill swordfish a 4-yr averaging period was employed in computing the equilibrium effort statistic while a 2-yr smoothing was applied to the sailfish-spearfish data. Dummy effort values were added at the beginning of each series so that all data points could be retained in the analysis.

The model fitted was

$$U_i = (\alpha + \beta \bar{E}_i)^{(\frac{1}{m-1})} + \gamma_i$$

where U_i = equilibrium abundance index for year i

$\bar{E}_i$ = smoothed effective fishing effort (equilibrium approximation) in year i

γ_i = random error term.

PRODFIT finds α, β, and m such that

$$S = \sum_i (U_i - \hat{U}_i)^2 = \sum_i \gamma_i^2$$

is minimum. The estimates of α, β, and m yield three quantities of particular interest:

(1) the estimated MSY

$$C_{max} = (\alpha - \alpha m)(\alpha/m)^{\left(\frac{1}{m-1}\right)} \Big/ m\beta$$

(2) the associated "optimum" effort

$$E_{opt} = (\alpha - \alpha m) \Big/ m\beta$$

(3) the "optimum" value of the abundance index

$$U_{opt} = C_{max} \Big/ E_{opt} = (\alpha/m)^{\left(\frac{1}{m-1}\right)}.$$

The general approach was to estimate all three parameters simultaneously, i.e., to let m vary. However, we also fixed m equal to 2 (Schaefer model) in several instances.

Below we present the results species by species.

Blue Marlin

15 The observed U_{1i} are plotted against E_{1i} in Figure 15 along with the
. 16 fitted production model. In Figure 16, U_{2i} is plotted against E_{2i}.
.e 12 In both cases the catch unit is number of fish. Table 12 lists the parameter estimates for these cases along with those for the corresponding catch-in-weight data.

Estimates of Pacific-wide MSY are practically identical for the central Pacific index (U_1 index) and total Pacific index (U_2 index), being 220,000 fish and 221,000 fish, respectively. For the corresponding

catch-in-weight indices, the MSY estimates are both 22,000 metric tons (MT). MSY in terms of weight is achieved at somewhat lower effort than MSY in number of fish.

The plot of equilibrium yield versus effective effort is shown in Figure 17 for the total Pacific index ($U_2 \times \bar{E}_2$ vs. $\bar{E}_2$). As the figure shows, the "optimum" effort level for blue marlin harvest has been exceeded every year since 1961, and 1975 effort was at about twice the "optimum" level.

ig. 17

Striped Marlin

Production model results for the total Pacific index of striped marlin abundance are listed in Table 13. When m was allowed to vary freely in the estimation, the resulting estimates of m were 0, suggesting that the equilibrium yield and effort curve for striped marlin is not dome-shaped as with blue marlin, but is asymptotic to MSY. However, the estimated MSY (817,000 fish or 54,500 MT) far exceeds any observed values in spite of a long history of exploitation, and is considered unreasonable. We therefore reapplied the model with m fixed at 2.0. The results in this case were $\hat{MSY}$ = 390,000 fish or 21,000 MT. The estimated MSY would be achieved at an effective effort level somewhat greater than that applied in 1975 (Figure 18).

able 13

Fig. 18

Black Marlin

When m was allowed to vary, the southwest area abundance index, U_1, yielded, at $\hat{m}$ = 0.29, an estimated MSY of 42,700 fish taken at $\hat{E}_{opt}$ = 11.4 million effective hooks (Table 14). These results seemed

Table 14

unreasonable, and so again the production model was fitted with m fixed at 2.0. Results in this instance were $\hat{MSY}$ = 34,900 fish and $\hat{E}_{opt}$ = 69.3 million effective hooks. The effective effort in 1975 was about 82 million hooks.

When the U_2 index for the total Pacific was considered, MSY was estimated to be 34,200 fish and $\hat{E}_{opt}$ = 228 million effective
ig. 19 hooks, with m fixed at 2.0 (Figure 19). When m was allowed to vary, the results were $\hat{MSY}$ = 29,600 fish and $\hat{E}_{opt}$ = 169 million effective hooks, at $\hat{m}$ = 0.58. In both sets of results using the total Pacific index, the estimated E_{opt} is less than the 1975 effective effort of
ig. 20 about 280 million hooks (Figure 20).

Sailfish-Spearfish

Production model results for the sailfish-spearfish group,
able 15 using the Pacific-wide data (U_2 and E_2) are listed in Table 15. When m is permitted to vary, it is estimated as 0, and MSY is estimated to be 874,000 fish or 21,000 MT. With m fixed at 2.0, $\hat{MSY}$ = 446,000 fish (11,800 MT) achieved at an effective effort of 491 million hooks (482 million hooks). In the 1972-75 period effort
ig. 21 did not exceed 325 million hooks (Figure 21).

Swordfish

A production model for swordfish, Pacific-wide, is shown in
g. 22 Figure 22. The estimated MSY, with m fixed at 2.0, is 278,000 fish, and $\hat{E}_{opt}$ = 601,000 effective hooks. This effort is above the effort level of recent years.

CONCLUSIONS AND EVALUATIONS

The results presented above are provisional and should be viewed circumspectly. Some data sets and model fits inspire more confidence than others, and there is some danger that a data set's "good looks" will color our judgment of the parameter estimates unduly. This is a hazard in all modeling, and the only safeguard is a thorough validation of the model's assumptions. On the other hand, if enough detailed data were available on billfish population dynamics to permit a complete test of the production model assumptions, it would probably be possible to avoid the simple production model altogether and use a more elaborate approach to stock assessment.

In lieu of detailed data, simulation studies would shed some light on the robustness of the production model and should be undertaken. But where possible, some of the basic assumptions should be examined directly. For example, all the analyses here assumed a constant catchability coefficient, but changes in fish targets or harvest strategies may alter this parameter. Suzuki and Warashina (1977) have shown that recent increases in the fishing depth of tuna longline gear deployed in the central and western equatorial Pacific, while nearly doubling the catch rates of the target bigeye tuna,

Thunnus obesus, have also affected catch rates of billfishes. They reported the following ratios of catch rates using the new gear versus the standard gear:

Species	Catch rate ratio deep/regular
Sailfish	0.07
Striped marlin	0.28
Black marlin	0.34
Blue marlin	0.56
Swordfish	0.79
Albacore, Thunnus alalunga	0.82
Yellowfin tuna, T. albacares	0.73
Bigeye tuna	1.79

The use of such deep longline gear may have altered the catchability coefficients in 1975. And considering the apparent impact on catch rates of billfishes, exhaustive comparative studies will be required to evaluate possible changes in abundance indices.

Other critical assumptions concern stock boundaries, and the index areas assumed in our analyses may be incorrect. In the case of striped marlin and sailfish, where more than one stock may exist, the subarea indices of abundance and effective effort were either inconsistent with the production model or too ill-behaved to permit a reliable production model assessment. On the other hand, the total Pacific indices for these two species gave reasonable results.

In spite of these uncertainties and other possible shortcomings, the production model analyses permit a rough characterization of the status of Pacific billfish stocks. Referring to the MSY criterion of the simple, deterministic equilibrium yield model, the analyses suggest that the catches of striped marlin and sailfish are still somewhat below MSY. Similarly, the data for swordfish do not indicate overexploitation. However, blue marlin and black marlin seem clearly to be overexploited on the basis of the MSY criterion.

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Table 1.--Blue marlin, central Pacific index area, U_1 and E_1.

Year	U (fish/10^3 hooks)	C. Japan (10^3 fish)	Raising factor	C. Total (10^3 fish)	Average weight (kg/fish)	C. Total (MT)	E (10^6 hooks)
1949							5.0*
1950							10.0*
1951							20.0*
1952	5.15	172.7	1.00	172.7	51.0	8.8	33.5
1953	4.74	192.0	1.00	192.0	83.3	16.0	40.5
1954	3.55	139.5	1.00	139.5	131.9	18.4	39.3
1955	3.51	257.6	1.00	257.6	82.7	21.3	73.4
1956	3.49	189.5	1.00	189.5	128.8	24.4	54.3
1957	3.15	242.0	1.00	242.0	128.5	31.1	76.8
1958	2.94	237.3	1.00	237.3	123.0	29.2	80.7
1959	2.49	209.9	1.00	209.9	119.6	25.1	84.3
1960	2.14	187.2	1.00	187.2	126.1	23.6	87.5
1961	2.19	285.8	1.00	285.8	82.2	23.5	130.5
1962	2.01	352.7	1.00	352.7	63.5	22.4	175.5
1963	1.59	300.0	1.00	300.0	85.7	25.7	188.7
1964	1.46	223.9	1.00	223.9	89.3	20.0	153.4
1965	1.06	172.5	1.00	172.5	93.3	16.1	162.7
1966	1.16	150.1	1.05	157.6	107.9	17.0	135.9
1967	1.12	143.6	1.13	162.3	91.2	14.8	144.9
1968	0.93	126.3	1.07	135.1	91.8	12.4	145.3
1969	1.08	144.9	1.07	155.0	83.5	12.9	143.5
1970	1.30	180.2	1.13	203.6	76.6	15.6	156.6
1971	0.88	102.5	1.30	133.2	70.2	9.4	151.4
1972	0.86	128.2	1.30	166.7	71.8	12.0	193.8
1973	0.89	128.6	1.30	167.2	75.4	12.6	187.9
1974	0.68	121.1	1.20	145.3	69.4	10.1	213.7
1975	0.48	85.7	1.25	107.1	85.2	9.1	223.1

*Dummy values.

Table 2.--Blue marlin, total Pacific index area, U_2 and E_2.

Year	U (fish/10^3 hooks)	C. Japan (10^3 fish)	Raising factor	C. Total (10^3 fish)	Average weight (kg/fish)	C. Total (MT)	E (10^6 hooks)
1949							10.0*
1950							20.0*
1951							40.0*
1952	2.83	172.7	1.00	172.7	51.0	8.8	61.0
1953	2.71	192.0	1.00	192.0	83.3	16.0	70.8
1954	2.14	124.5	1.00	124.5	147.8	18.4	58.2
1955	2.40	257.6	1.00	257.6	82.7	21.3	107.3
1956	2.29	189.5	1.00	189.5	128.8	24.4	82.8
1957	1.90	242.0	1.00	242.0	128.5	31.1	127.4
1958	1.65	237.3	1.00	237.3	123.0	29.2	143.8
1959	1.39	209.9	1.00	209.9	119.6	25.1	151.0
1960	1.26	187.2	1.00	187.2	126.1	23.6	148.6
1961	1.46	285.8	1.00	285.8	82.2	23.5	195.8
1962	1.26	352.7	1.00	352.7	63.5	22.4	279.9
1963	1.09	300.0	1.00	300.0	85.7	25.7	275.2
1964	0.96	223.9	1.00	223.9	89.3	20.0	233.2
1965	0.73	172.5	1.00	172.5	93.3	16.1	236.3
1966	0.72	150.1	1.05	157.6	107.9	17.0	218.9
1967	0.68	143.6	1.13	162.3	91.2	14.8	238.7
1968	0.63	126.3	1.07	135.1	91.8	12.4	214.4
1969	0.68	144.9	1.07	155.0	83.5	12.9	227.9
1970	0.79	180.2	1.13	203.6	76.6	15.6	257.7
1971	0.50	102.5	1.30	133.2	70.2	9.4	266.4
1972	0.56	128.2	1.30	166.7	71.8	12.0	297.7
1973	0.57	128.6	1.30	167.2	75.4	12.6	293.3
1974	0.46	121.1	1.20	145.3	69.4	10.1	315.9
1975	0.35	85.7	1.25	107.1	85.2	9.1	306.0

*Dummy values.

Table 3.--Striped marlin, North Pacific index area, U_1 and E_1.

Year	U (fish/10^3 hooks)	C. Japan (10^3 fish)	Raising factor	C. Total (10^3 fish)	Average weight (kg/fish)	C. Total (MT)	E (10^6 hooks)
1949							5.0*
1950							20.0*
1951							40.0*
1952	1.69	92.7	1.00	92.7			54.8
1953	1.09	68.4	1.00	68.4			62.8
1954	1.13	104.9	1.00	104.9			92.8
1955	1.24	117.9	1.00	117.9			95.1
1956	1.44	127.2	1.00	127.2			88.3
1957	1.30	98.6	1.00	98.6			75.8
1958	1.42	122.6	1.00	122.6			86.3
1959	1.60	120.5	1.00	120.5			75.3
1960	1.29	119.0	1.00	119.0			92.2
1961	1.29	101.4	1.00	101.4			78.6
1962	1.66	110.6	1.00	110.6			66.6
1963	1.28	91.0	1.00	91.0			71.1
1964	2.70	139.0	1.00	139.0			51.5
1965	1.88	120.5	1.00	120.5			64.1
1966	1.51	77.3	1.00	77.3			51.2
1967	1.85	137.1	1.00	137.1			74.1
1968	1.93	118.1	1.00	118.1			61.2
1969	1.25	80.3	1.00	80.3			64.2
1970	2.36	195.0	1.00	195.0			82.6
1971	1.52	104.6	1.00	104.6			68.8
1972	0.81	51.94	1.00	51.94			64.1
1973	1.00	70.10	1.00	70.10			70.1
1974	0.97	64.2	1.00	64.2			66.2
1975	0.80	40.18	1.00	40.18			50.2

*Dummy values.

Table 4.--Striped marlin, South Pacific index area, U_1 and E_1.

Year	U (fish/10^3 hooks)	C. Japan (10^3 fish)	Raising factor	C. Total (10^3 fish)	Average weight (kg/fish)	C. Total (MT)	E (10^6 hooks)
1949							0.0*
1950							0.0*
1951							0.0*
1952	3.57	0.03	1.00	0.03			.008
1953	1.86	12.9	1.00	12.9			6.9
1954	2.89	78.9	1.00	78.9			27.3
1955	1.73	47.4	1.00	47.4			27.4
1956	1.59	30.8	1.00	30.8			19.4
1957	1.19	21.5	1.00	21.5			18.1
1958	1.29	36.9	1.00	36.9			28.6
1959	1.00	27.6	1.00	27.6			27.6
1960	1.18	28.5	1.00	28.5			24.2
1961	1.29	38.0	1.00	38.0			29.4
1962	1.09	67.3	1.00	67.3			61.7
1963	0.83	40.6	1.00	40.6			48.9
1964	0.79	25.0	1.00	25.0			31.6
1965	0.71	22.4	1.00	22.4			31.5
1966	0.58	26.0	1.01	26.3			45.3
1967	0.57	13.9	1.02	14.2			24.9
1968	0.69	9.9	1.01	10.0			14.5
1969	0.77	9.8	1.02	10.0			13.0
1970	1.24	23.6	1.03	24.3			19.6
1971	1.04	19.4	1.07	20.8			20.0
1972	1.46	17.9	1.07	19.2			13.2
1973	1.14	17.7	1.07	18.8			16.5
1974	0.87	14.4	1.06	15.3			17.6
1975	1.04	9.6	1.06	10.2			9.8

*Dummy values.

Table 5.--Striped marlin, eastern Pacific index area, U_1 and E_1.

Year	U (fish/10^3 hooks)	C. Japan (10^3 fish)	Raising factor	C. Total (10^3 fish)	Average weight (kg/fish)	C. Total (MT)	E. (10^6 hooks)
1952	0.00	0.00	1.00	0.00			0.00
1953	0.00	0.00	1.00	0.00			0.00
1954	1.57	0.04	1.00	0.04			0.025
1955	0.35	0.08	1.00	0.08			0.23
1956	1.06	0.23	1.00	0.23			0.22
1957	0.58	1.43	1.00	1.43			2.46
1958	0.77	3.50	1.00	3.50			4.54
1959	1.03	3.32	1.00	3.32			3.22
1960	1.14	4.70	1.00	4.70			4.12
1961	3.05	45.6	1.00	45.6			14.95
1962	4.55	141.4	1.00	141.4			31.1
1963	3.94	148.2	1.00	148.2			37.6
1964	3.35	270.7	1.00	270.7			80.8
1965	4.02	236.9	1.00	236.9			58.9
1966	3.71	223.4	1.01	225.6			60.8
1967	4.27	229.4	1.02	234.0			54.8
1968	3.78	339.1	1.01	342.5			90.6
1969	2.91	207.7	1.01	209.8			72.1
1970	3.10	183.4	1.02	187.1			60.4
1971	4.74	228.7	1.03	235.6			49.7
1972	2.65	172.3	1.07	184.4			69.6
1973	1.23	105.1	1.07	112.5			91.5
1974	1.98	133.1	1.06	141.1			71.3
1975	2.03	125.3	1.06	132.8			65.4

Table 6.--Striped marlin, total Pacific index area, U_2 and E_2.

Year	U (fish/10^3 hooks)	C. Japan (10^3 fish)	Raising factor	C. Total (10^3 fish)	Average weight (kg/fish)	C. Total (MT)	E (10^6 hooks)
1949	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15.0*
1950							15.0*
1951							30.0*
1952	2.40	95.9	1.00	95.9	41.7	4.0	40.0
1953	2.10	85.0	1.00	85.0	36.5	3.1	40.5
1954	3.11	186.9	1.00	186.9	43.9	8.2	60.1
1955	2.12	171.4	1.00	171.4	33.8	5.8	80.8
1956	2.38	164.2	1.00	164.2	45.1	7.4	69.0
1957	2.04	132.2	1.00	132.2	53.0	7.0	64.8
1958	1.92	175.5	1.00	175.5	57.0	10.0	91.4
1959	1.50	167.9	1.00	167.9	61.9	10.4	111.9
1960	1.24	161.1	1.00	161.1	53.4	8.6	129.9
1961	1.59	218.3	1.00	218.3	43.1	9.4	137.3
1962	1.93	348.5	1.00	348.5	44.2	15.4	180.6
1963	1.61	317.8	1.00	317.8	50.3	16.0	197.4
1964	1.81	508.9	1.00	508.9	46.2	23.5	281.2
1965	1.60	422.1	1.00	422.1	51.9	21.9	263.8
1966	1.50	350.8	1.01	354.3	55.3	19.6	236.2
1967	1.56	405.9	1.02	414.0	46.6	19.3	265.4
1968	1.70	507.2	1.01	512.3	41.2	21.1	301.4
1969	1.12	323.4	1.01	326.6	60.6	19.8	291.6
1970	1.68	457.1	1.02	466.2	46.2	21.5	277.5
1971	1.78	394.0	1.03	405.8	54.6	22.2	228.0
1972	1.12	270.2	1.07	289.1	49.2	14.2	258.1
1973	0.80	230.7	1.07	246.8	61.6	15.2	308.5
1974	0.94	238.2	1.06	252.5	56.7	14.3	268.6
1975	0.84	194.1	1.06	205.7	75.7	15.6	244.9

*Dummy values.

Table 7.--Sailfish-spearfish, total Pacific index area, U_2 and E_2.

Year	U (fish/10^3 hooks)	C. Japan (10^3 fish)	Raising factor	C. Total (10^3 fish)	Average weight (kg/fish)	C. Total (MT)	E (10^6 hooks)
1951							20.0*
1952	1.98	41.5	1.75	72.6	27.6	2.0	36.7
1953	2.51	68.1	1.75	119.2	27.6	3.3	47.5
1954	1.36	50.4	1.75	88.2	27.6	2.4	64.9
1955	1.76	68.9	1.75	120.6	27.6	3.3	68.5
1956	1.82	66.0	1.75	115.5	27.6	3.2	63.5
1957	1.67	85.8	2.00	171.6	16.3	2.8	102.8
1958	1.49	72.6	1.68	122.0	27.5	3.4	81.9
1959	1.96	92.8	1.53	142.0	25.9	3.7	72.4
1960	1.29	67.3	1.92	129.2	38.6	5.0	100.2
1961	1.13	88.0	1.73	152.2	31.8	4.8	134.7
1962	1.04	132.7	1.63	216.3	31.6	6.8	208.0
1963	1.39	161.6	1.79	289.3	27.2	7.9	208.1
1964	0.97	148.2	1.69	250.4	24.3	6.1	258.1
1965	1.66	494.3	1.21	598.1	21.4	12.8	360.3
1966	1.19	313.2	1.39	435.3	25.5	11.1	365.8
1967	1.43	350.6	1.39	487.3	24.2	11.8	340.8
1968	1.12	454.0	1.49	676.5	18.5	12.5	604.0
1969	0.93	229.8	1.45	333.2	38.3	12.8	358.3
1970	1.13	323.9	1.44	466.4	19.4	9.0	412.7
1971	0.84	195.7	1.33	260.3	31.2	8.1	309.9
1972	0.74	193.3	1.19	230.0	37.2	8.6	310.8
1973	0.92	230.8	1.34	309.3	28.2	8.7	336.2
1974	0.93	213.0	1.19	253.5	28.2	7.1	272.6
1975	0.70	151.8	1.26	191.3	29.0	5.5	273.3

*Dummy values.

Table 8.---Sailfish-spearfish, eastern Pacific index area, U_1 and E_1.

Year	U (fish/10^3 hooks)	C. Japan (10^3 fish)	Raising factor	C. Total (10^3 fish)	Average weight (kg/fish)	C. Total (MT)	E (10^6 hooks)
1952	0.00	0.00	1.00	0.00			0.00
1953	0.00	0.00	1.00	0.00			0.00
1954	0.35	0.01	1.00	0.01			0.03
1955	0.39	0.03	1.00	0.03			0.08
1956	0.26	0.11	1.00	0.11			0.42
1957	0.09	0.61	1.00	0.61			6.78
1958	0.17	0.42	1.00	0.42			2.47
1959	0.06	0.15	1.00	0.15			2.50
1960	0.07	0.44	1.00	0.44			6.29
1961	0.50	6.72	1.00	6.72			13.44
1962	0.40	12.75	1.00	12.75			31.88
1963	0.98	35.28	1.00	35.28			36.00
1964	2.86	87.28	1.00	87.28			30.52
1965	6.01	418.60	1.00	418.60			69.65
1966	4.63	232.85	1.00	232.85			50.29
1967	6.27	283.97	1.00	283.97			45.29
1968	4.82	398.00	1.00	398.00			82.57
1969	4.42	193.62	1.00	193.62			43.81
1970	4.84	268.15	1.00	268.15			55.40
1971	3.87	155.17	1.00	155.17			40.10
1972	2.89	154.17	1.00	154.17			53.35
1973	4.47	171.04	1.00	171.04			38.26
1974	4.03	166.49	1.00	166.49			41.31
1975	4.33	117.43	1.00	117.43			27.12

Table 9.--Black marlin, southwest Pacific index area, U_1 and E_1.

Year	U (fish/10^3 hooks)	C. Japan (10^3 fish)	Raising factor	C. Total (10^3 fish)	Average weight (kg/fish)	C. Total (MT)	E (10^6 hooks)
1949							10.0*
1950							20.0*
1951							40.0*
1952	0.35	19.2	1.00	19.2			54.9
1953	0.81	34.2	1.00	34.2			42.2
1954	0.99	47.2	1.00	47.2			47.7
1955	0.90	39.5	1.00	39.5			43.9
1956	0.92	45.1	1.00	45.1			49.0
1957	0.62	51.7	1.00	51.7			83.4
1958	0.51	28.4	1.00	28.4			55.7
1959	0.40	21.5	1.00	21.5			53.8
1960	0.40	21.5	1.00	21.5			53.8
1961	0.40	27.7	1.00	27.7			69.2
1962	0.34	34.8	1.00	34.8			102.4
1963	0.31	30.1	1.00	30.1			97.1
1964	0.28	26.6	1.00	26.6			95.0
1965	0.36	38.0	1.00	38.0			105.6
1966	0.27	34.0	1.08	36.7			135.9
1967	0.29	22.3	1.14	25.4			87.6
1968	0.23	17.0	1.15	19.6			85.2
1969	0.21	22.0	1.14	25.1			119.5
1970	0.22	18.1	1.22	22.1			100.5
1971	0.34	19.2	1.27	24.4			71.8
1972	0.24	17.2	1.19	20.5			85.4
1973	0.23	17.7	1.19	21.1			91.7
1974	0.18	13.3	1.17	15.6			86.7
1975	0.19	10.2	1.17	11.9			62.6

*Dummy values.

Table 10.--Black marlin, total Pacific index area, U_2 and E_2.

Year	U (fish/10^3 hooks)	C. Japan (10^3 fish)	Raising factor	C. Total (10^3 fish)	Average weight (kg/fish)	C. Total (MT)	E (10^5 hooks)
1949							10.0*
1950							30.0*
1951							60.0*
1952	0.24	19.2	1.00	19.2			80.0
1953	0.35	34.2	1.00	34.2			97.7
1954	0.28	47.2	1.00	47.2			168.6
1955	0.29	39.5	1.00	39.5			136.2
1956	0.29	45.1	1.00	45.1			155.5
1957	0.17	51.7	1.00	51.7			304.1
1958	0.13	28.4	1.00	28.4			218.5
1959	0.13	21.5	1.00	21.5			165.4
1960	0.12	21.5	1.00	21.5			179.2
1961	0.13	27.7	1.00	27.7			213.1
1962	0.11	34.8	1.00	34.8			316.4
1963	0.09	30.1	1.00	30.1			334.4
1964	0.10	26.6	1.00	26.6			266.0
1965	0.10	38.0	1.00	38.0			380.0
1966	0.08	34.0	1.08	36.7			458.8
1967	0.09	22.3	1.14	25.4			282.2
1968	0.07	17.0	1.15	19.6			280.0
1969	0.08	22.0	1.14	25.1			313.8
1970	0.07	18.1	1.22	22.1			315.7
1971	0.08	19.2	1.27	24.4			305.0
1972	0.10	17.2	1.19	20.5			205.0
1973	0.07	17.7	1.19	21.1			301.4
1974	0.05	13.3	1.17	15.6			312.0
1975	0.04	10.2	1.17	11.9			297.5

*Dummy values.

Table 11.--Swordfish, total Pacific index area, U_2 and E_2.

Year	U (fish/10^3 hooks)	C. Japan (10^3 fish)	Raising factor	C. Total (10^3 fish)	Average weight (kg/fish)	C. Total (MT)	E (10^6 hooks)
1949							100.0*
1950							200.0*
1951							300.0*
1952	0.52	177.1	1.08	191.2	49.7	9.5	367.7
1953	0.63	215.6	1.05	226.9	35.7	8.1	360.2
1954	0.62	259.9	1.00	259.8	33.1	8.6	419.0
1955	0.59	291.3	0.91	266.5	36.4	9.7	451.7
1956	0.53	210.6	0.91	192.2	53.6	10.3	362.6
1957	0.78	291.9	1.01	295.4	32.5	9.6	378.7
1958	0.87	380.0	0.95	361.6	31.8	11.5	415.6
1959	0.73	353.0	1.20	424.6	28.5	12.1	581.6
1960	0.68	405.4	0.88	357.4	33.3	11.9	525.6
1961	0.66	403.5	0.94	378.8	35.9	13.6	573.9
1962	0.48	224.5	0.91	203.4	76.2	15.5	423.8
1963	0.51	229.5	1.04	239.2	71.5	17.1	469.1
1964	0.42	174.9	1.10	192.2	92.6	17.8	457.6
1965	0.47	197.4	1.06	209.6	81.6	17.1	446.0
1966	0.46	231.1	1.08	248.7	79.6	19.8	540.7
1967	0.40	239.3	1.15	275.8	66.0	18.2	689.5
1968	0.40	225.2	1.12	253.1	71.9	18.2	632.8
1969	0.48	282.9	1.18	335.0	59.4	19.9	697.9
1970	0.46	196.8	1.27	249.4	81.8	20.4	542.2
1971	0.41	174.6	1.16	203.0	59.6	12.1	495.1
1972	0.48	172.4	1.20	207.3	60.3	12.5	431.9
1973	0.46	180.1	1.36	245.1	61.6	15.1	532.8
1974	0.46	161.4	1.20	193.8	65.0	12.6	421.3
1975	0.47	169.6	1.16	195.9	68.4	13.4	416.8

*Dummy values.

Table 12.--PRODFIT parameter estimates for blue marlin.

Case	$\hat{m}$	$\hat{C}_{max}$	$\hat{E}_{opt}$	$\hat{U}_{opt}$	$\hat{Q}$	$\hat{P}_o$	$\hat{P}_{opt}$
(1) Central Pacific Index area (U_1, E_1) T = 4	1.40	222×10^3 fish	98×10^6 hooks	2.2 fish/10^3 hooks	0.007	750×10^3 fish	324×10^3 fish
(2) Total Pacific (U_2, E_2) T = 4	1.54	221×10^3 fish	159×10^6 hooks	1.4 fish/10^3 hooks	0.006	503×10^3 fish	227×10^3 fish
(3) Central Pacific Index area (U_1, E_1) T = 4	1.41	22×10^3 MT	90.4×10^6 hooks	0.24 MT/10^3 hooks	0.012	45.3×10^3 MT	19.7×10^3 MT
(4) Total Pacific (U_2, E_2) T = 4	1.48	22×10^3 MT	141.8×10^6 hooks	0.16 MT/10^3 hooks	0.009	38.9×10^3 MT	17.2×10^3 MT

Table 13.--PRODFIT parameter estimates for striped marlin.

Case	$\hat{m}$	$\hat{C}_{max}$	$\hat{E}_{opt}$	$\hat{U}_{opt}$	$\hat{Q}$	$\hat{P}_o$	$\hat{P}_{opt}$
(1) Total Pacific (U_2, E_2) T = 4	2.0 fixed	390×10^3 fish	327×10^6 hooks	1.19 fish/10^3 hooks	0.002	118.5×10^4 fish	593×10^3 fish
(2) Total Pacific (U_2, E_2) T = 4	2.0 fixed	21.9×10^3 MT	411×10^6 hooks	0.05 MT/10^3 hooks	0.002	62.8×10^3 MT	31.4×10^3 MT
(3) Total Pacific (U_2, E_2) T = 4	0 $\rightarrow$	54.5×10^3 MT	$\rightarrow \infty$	$\rightarrow 0$			
(4) Total Pacific (U_2, E_2) T = 4	0 $\rightarrow$	817×10^3 fish	$\rightarrow \infty$	$\rightarrow 0$			

Table 14.--PRODFIT parameter estimates for black marlin.

Case	$\hat{m}$	$\hat{C}_{max}$	$\hat{E}_{opt}$	$\hat{U}_{opt}$	$\hat{Q}$	$\hat{P}_o$	$\hat{P}_{opt}$
(1) Southwest Index area (U_1, E_1) T = 4	2.0 fixed	34.9×10^3 fish	69.3×10^6 hooks	0.50 fish/10^3 hooks	0.018	56×10^3 fish	28×10^3 fish
(2) Total Pacific (U_2, E_2) T = 4	2.0 fixed	34.2×10^3 fish	228×10^6 hooks	0.15 fish/10^3 hooks	0.004	68.8×10^3 fish	34.4×10^3 fish
(3) Southwest Index area (U_1, E_1) T = 4	0.29	42.7×10^3 fish	11.4×10^6 hooks	3.8 fish/10^3 hooks	0.013	156×10^4 fish	279×10^3 fish
(4) Total Pacific (U_2, E_2) T = 4	0.58	29.6×10^3 fish	169×10^6 hooks	0.18 fish/10^3 hooks	0.003	182×10^3 fish	50.2×10^3 fish

Table 15.--PRODFIT parameter estimates for sailfish-spearfish.

Case	$\hat{m}$	$\hat{C}_{max}$	$\hat{E}_{opt}$	$\hat{U}_{opt}$	$\hat{Q}$	$\hat{P}_o$	$\hat{P}_{opt}$
(1) Total Pacific (U_2, E_2) T = 2	2.0 fixed	446×10^3 fish	491×10^6 hooks	0.91 fish/10^3 hooks	0.002	909×10^3 fish	454×10^3 fish
(2) Total Pacific (U_2, E_2) T = 2	2.0 fixed	11.8×10^3 MT	482×10^6 hooks	0.024 MT/10^3 hooks	0.0015	33.3×10^3 MT	16.6×10^3 MT
(3) Total Pacific (U_2, E_2) T = 2	$0 \rightarrow$	874×10^3 fish	$\rightarrow \infty$	$\rightarrow 0$			
(4) Total Pacific (U_2, E_2) T = 2	$0 \rightarrow$	21×10^3 MT	$\rightarrow \infty$	$\rightarrow 0$			

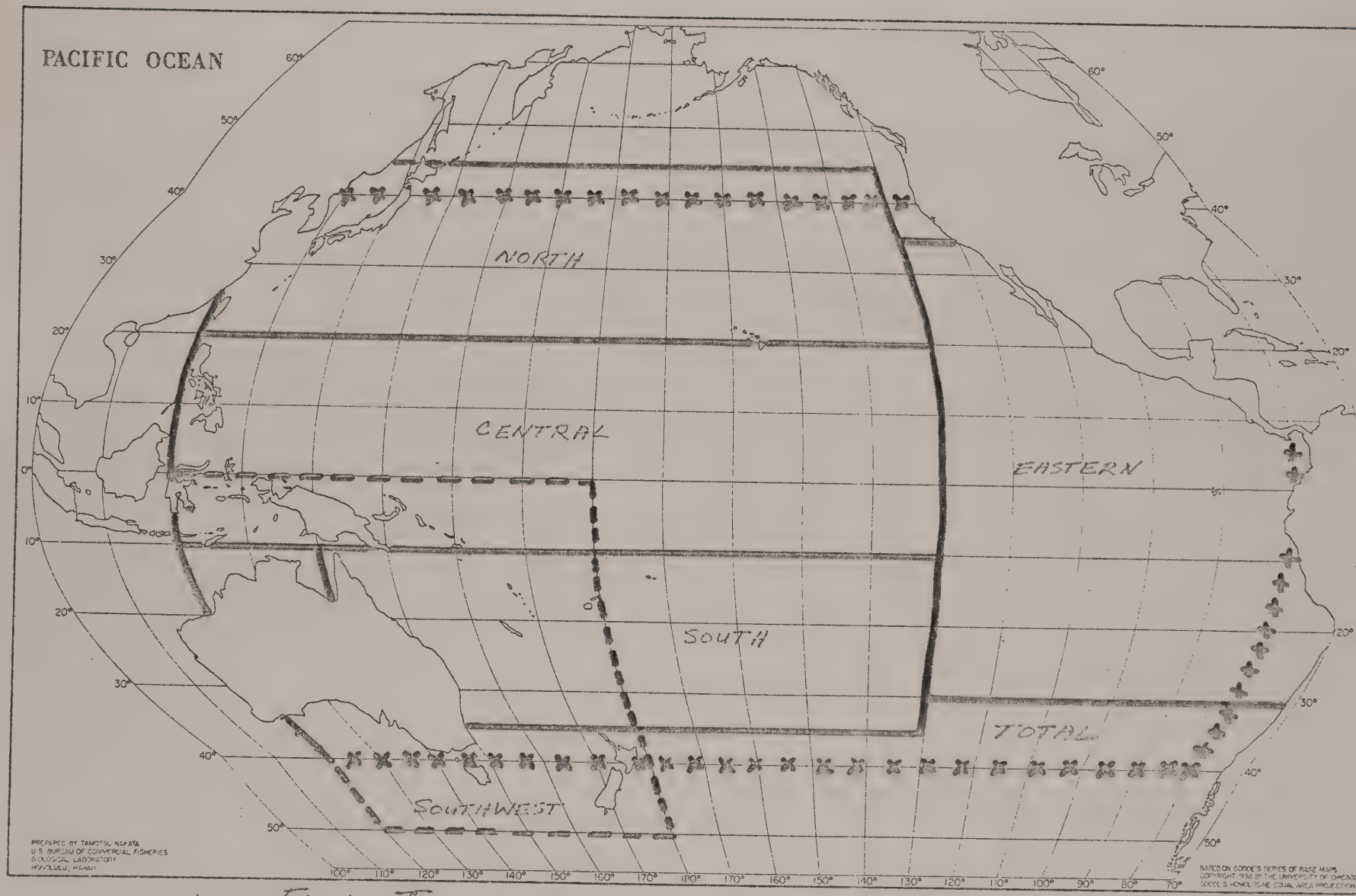

Fig. 1 - Index areas

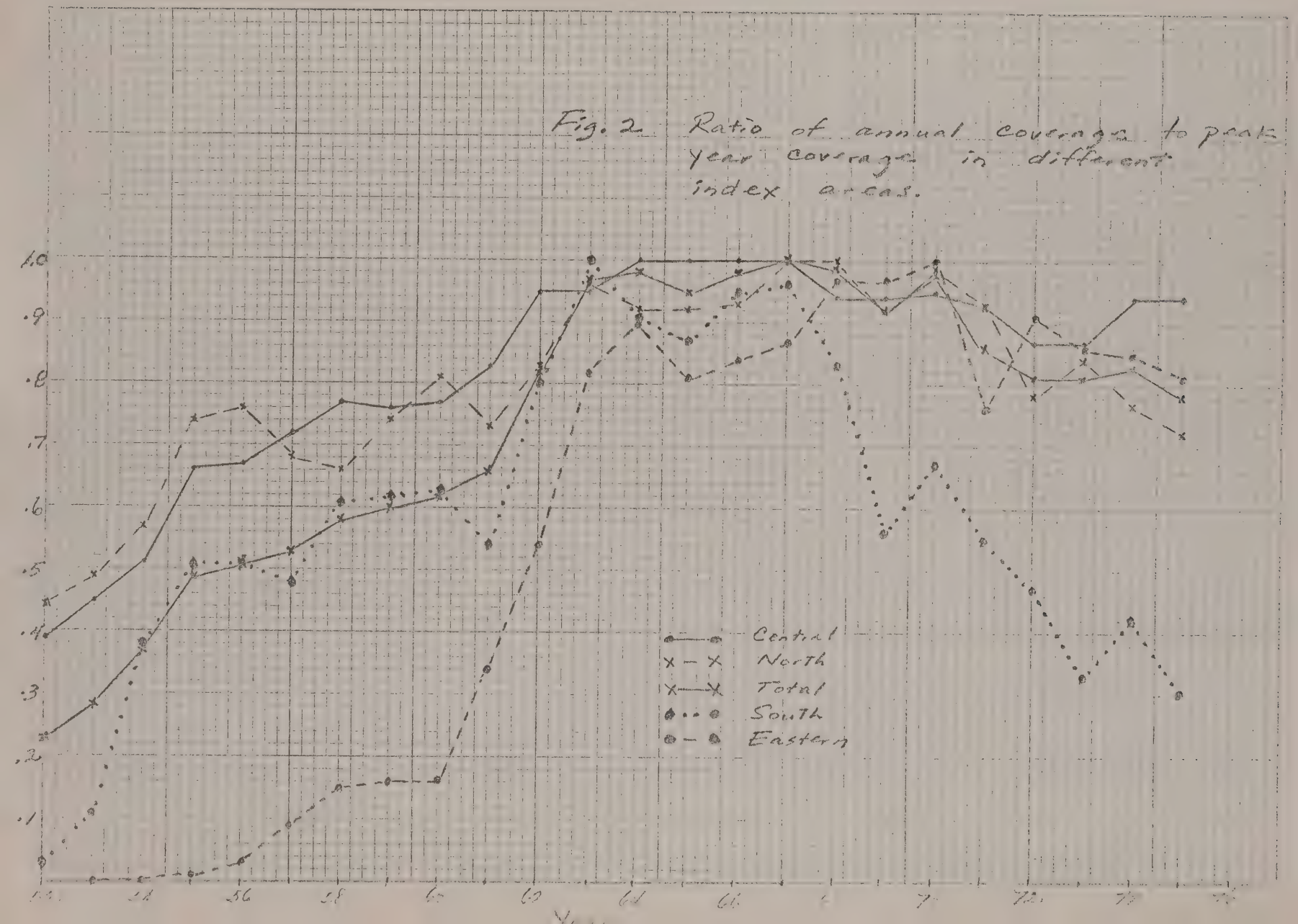
Fig. 2 Ratio of annual coverage to peak year coverage in different index areas.
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
Central
North
Total
South
Eastern

Fig. 3 Blue marlin, Central Pacific, U_1 (•) and E_1 (×)

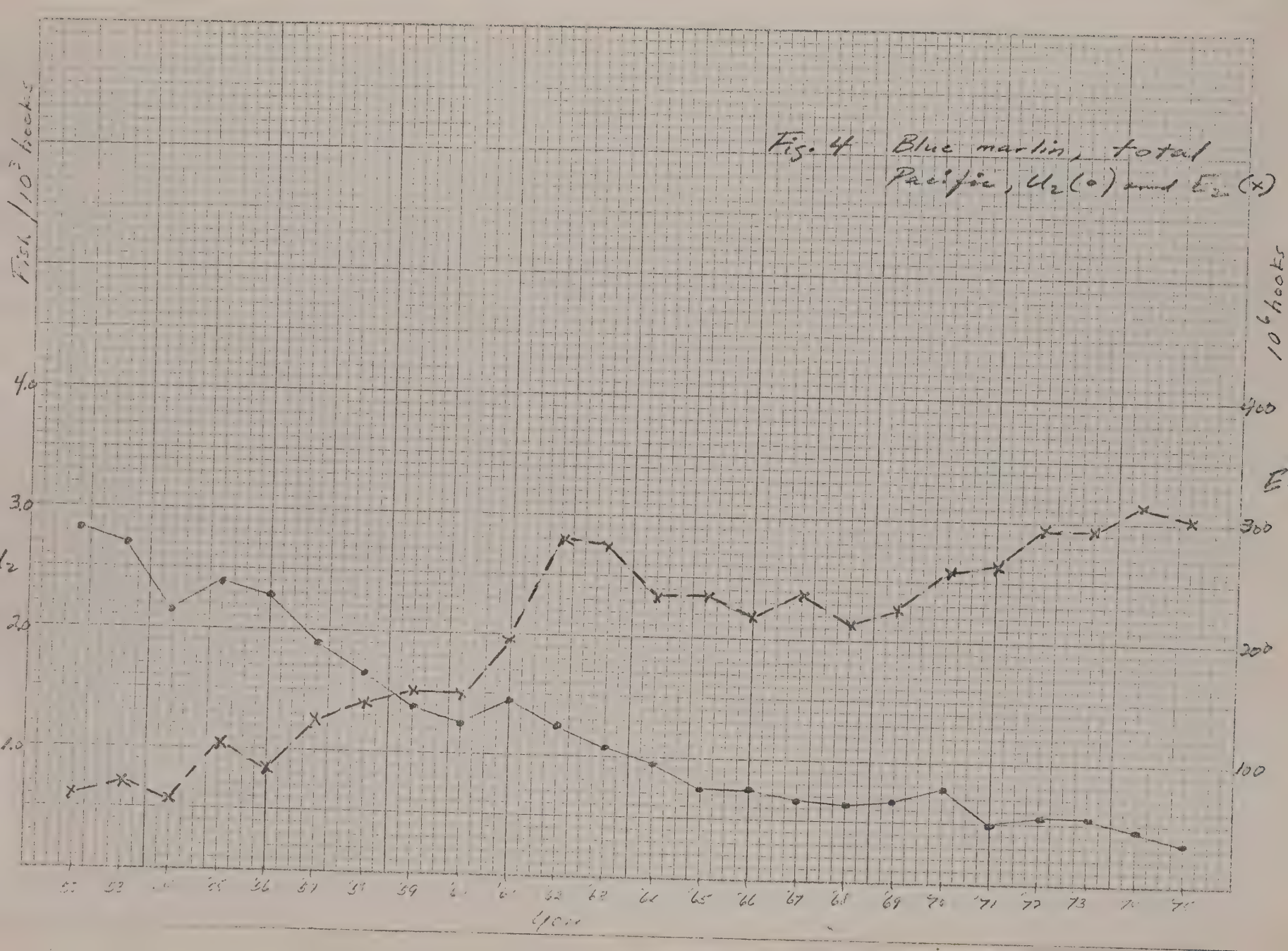
Fig. 4 Blue marlin, total Pacific, U_2 (o) and E_2 (x)
Fish / 10^2 hooks
10^6 hooks
U_2
E
4.0
3.0
2.0
1.0
400
300
200
100
55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73
Year

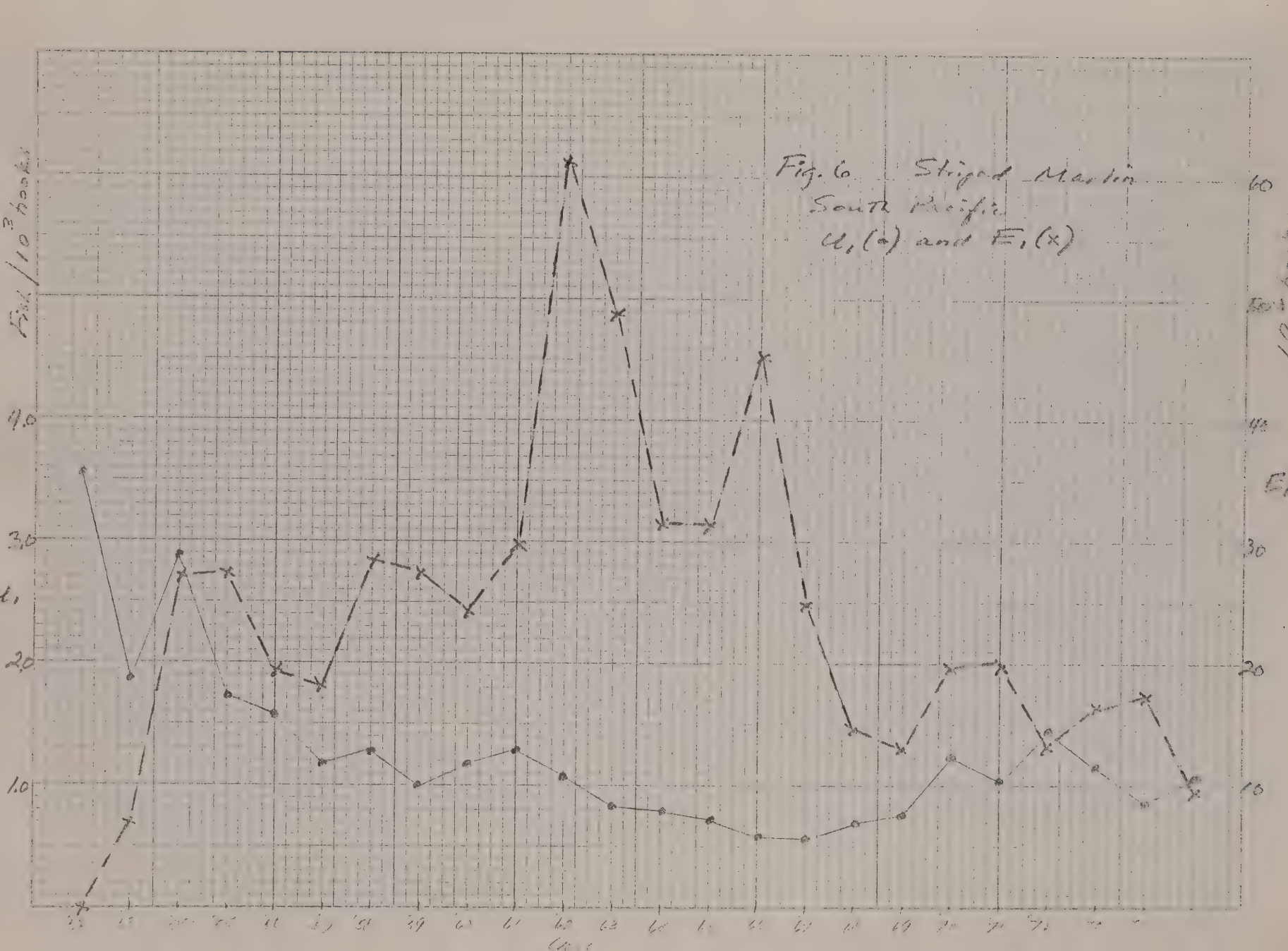
Fig. 6 Striped Marlin
South Pacific
u_1 (•) and E_1 (×)
Fish / 10 hooks
u_1
E_1
9.0
3.0
2.0
1.0
60
50
40
30
20
10

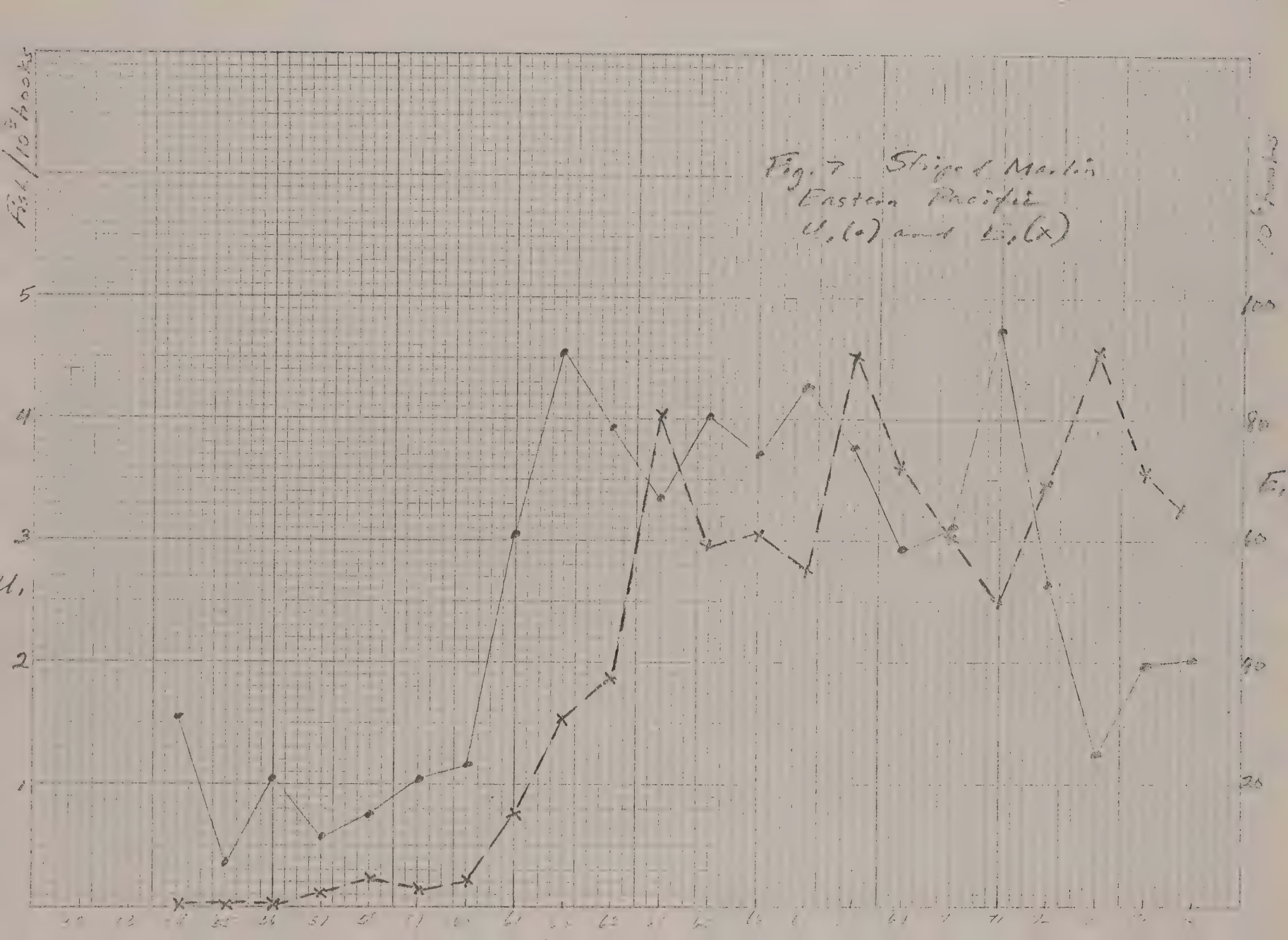
Fig. 7 Stigs & Mo. in Eastern Pacific
U_1 (o) and E_1 (x)
U_1
E_1

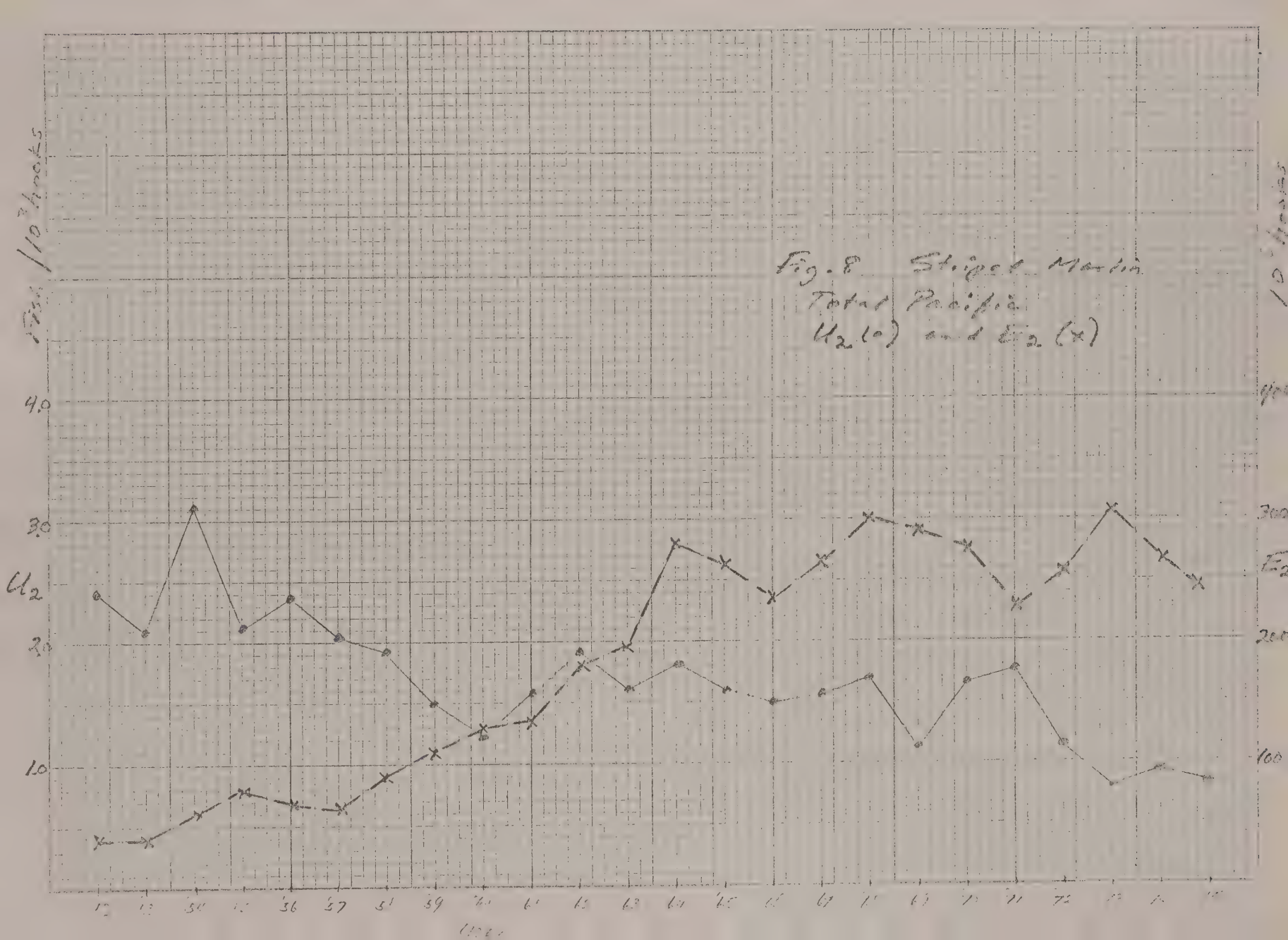

Fig. 8 Stigek Martin
Total Pacific
U_2 (o) and E_2 (x)

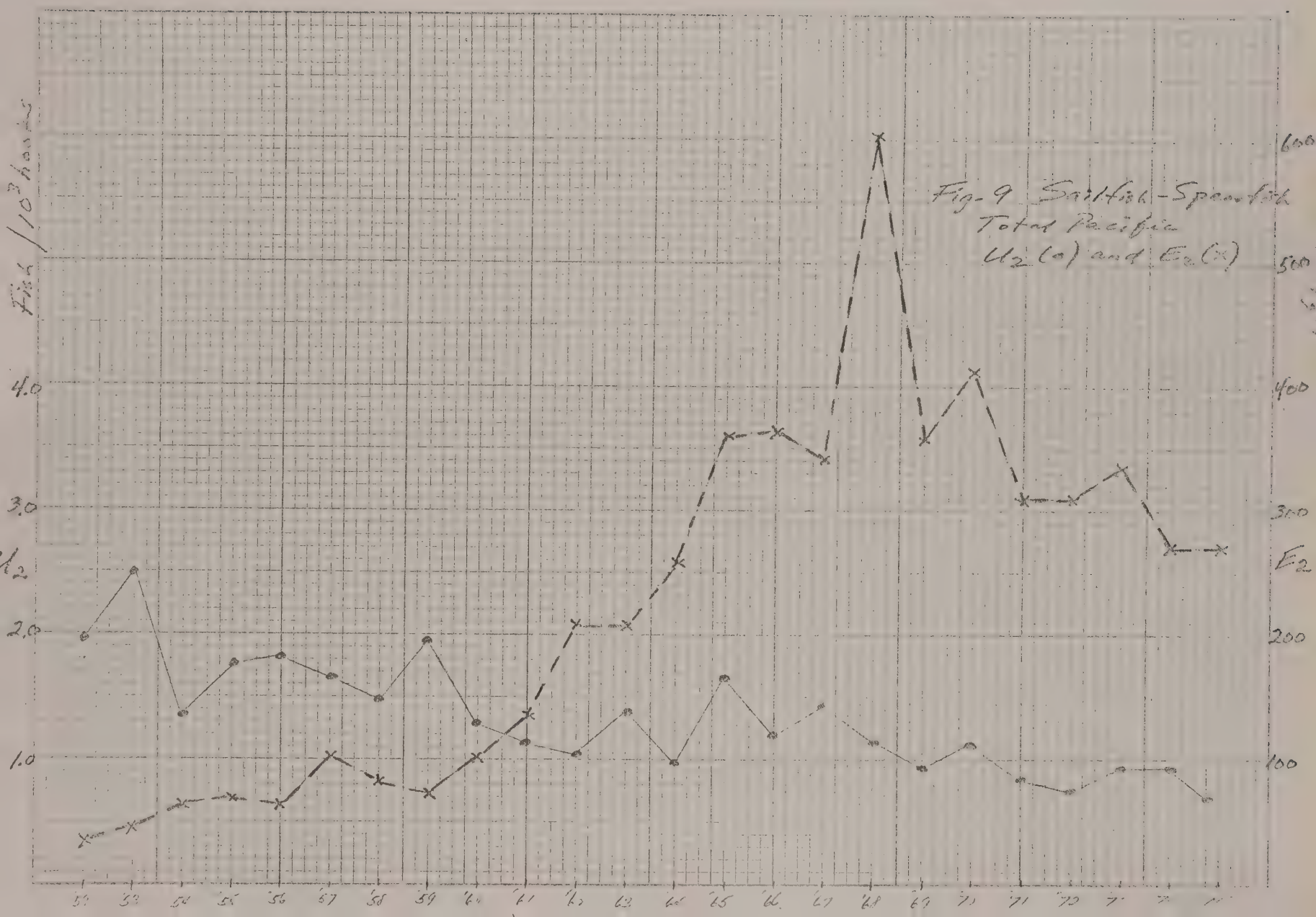
Fig-9 Saltfish-Spawner
Total Pacific
U_2 (o) and E_2 (x)
Fish / 10^3 hooks
U_2
E_2
4.0
3.0
2.0
1.0
600
500
400
300
200
100

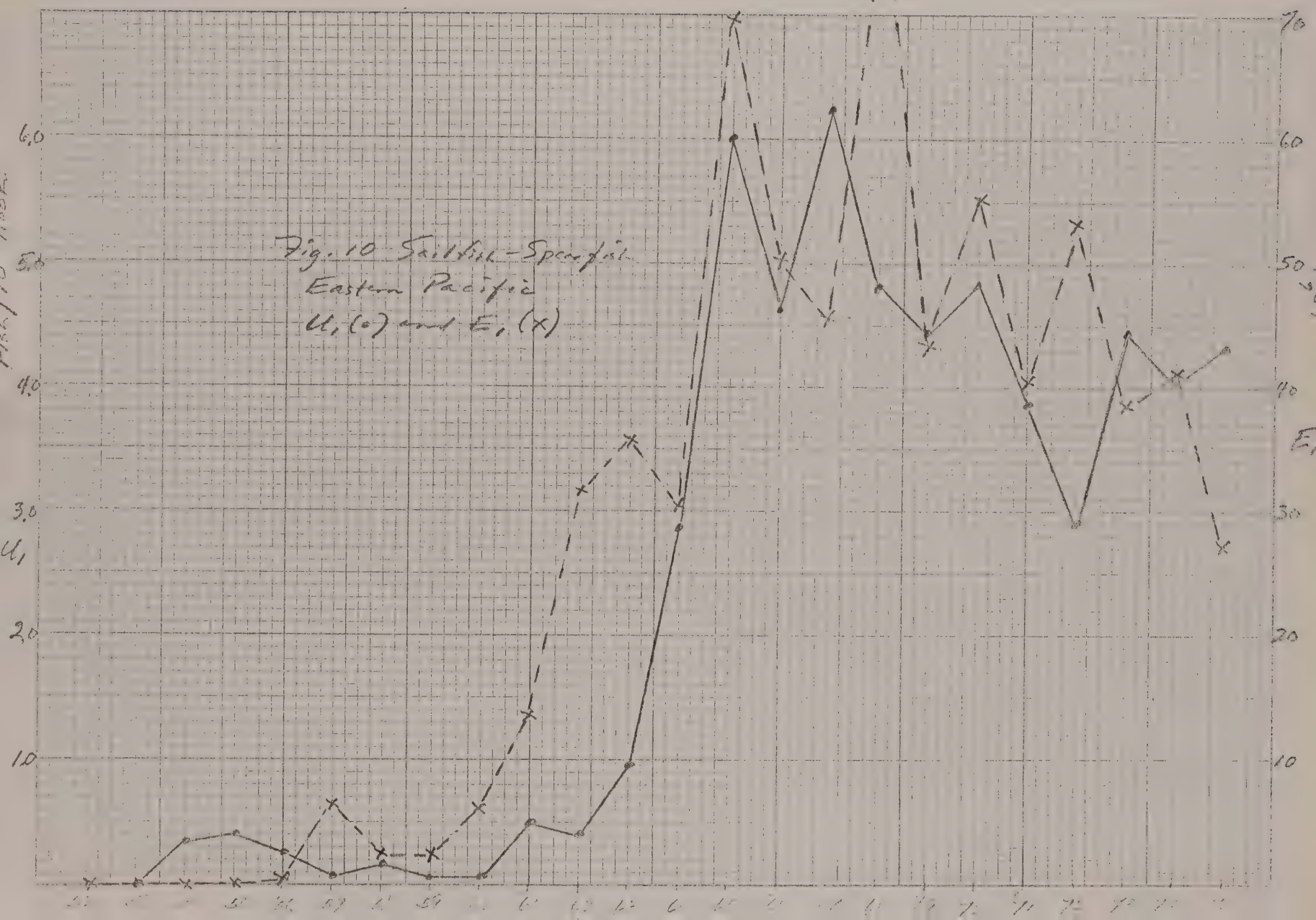

Fig. 10 Sailfish - Spearfish
Eastern Pacific
U_1 (○) and E_1 (×)

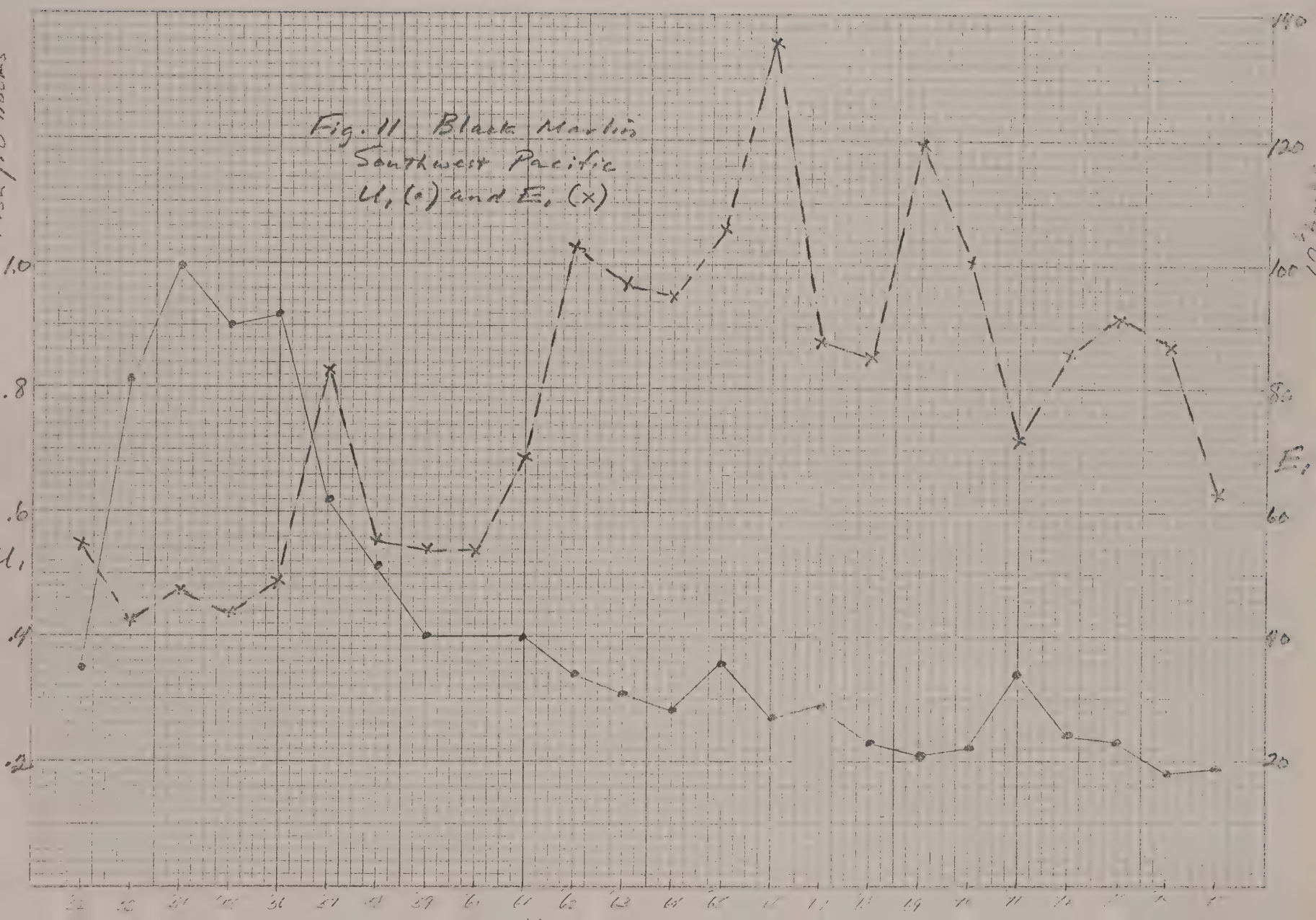
Fig. 11 Black Marlin
Southwest Pacific
U_1 (•) and E_1 (×)
1.0
.8
.6
.4
.2
120
100
80
60
40
20
E_1

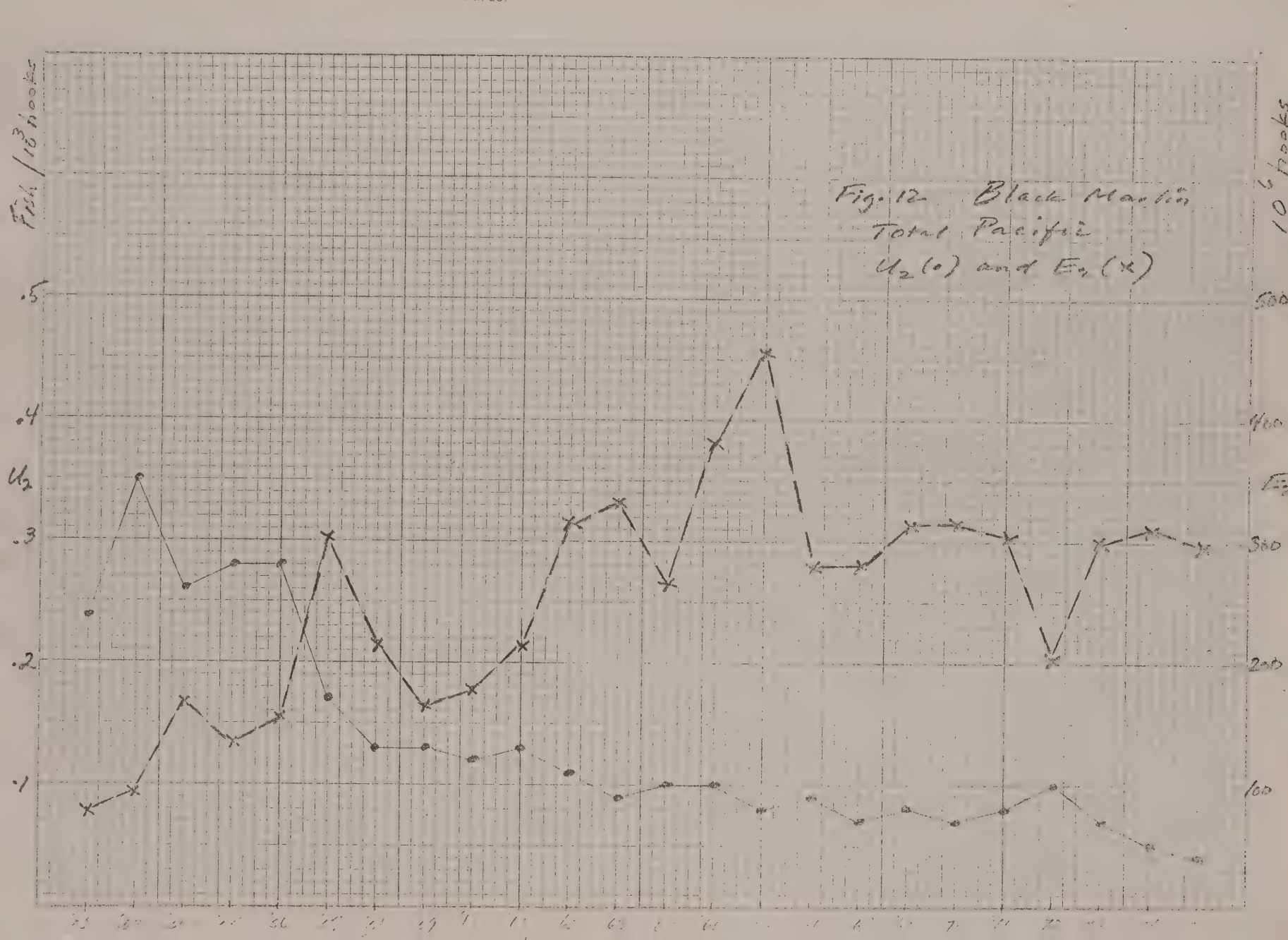

Fig. 12 Black Marlin
Total Pacific
U_2 (o) and E_2 (x)

Fig. 13 Swordfish
Total Pacific
$U_2(\circ)$ and $E_2(\times)$
Fish / 10 Hooks
1.0
.8
.6
.4
.2
U_2
700
600
500
400
300
200
100
E_2
50
54
56
58
60
62
64
66
68
70
72
74
Year

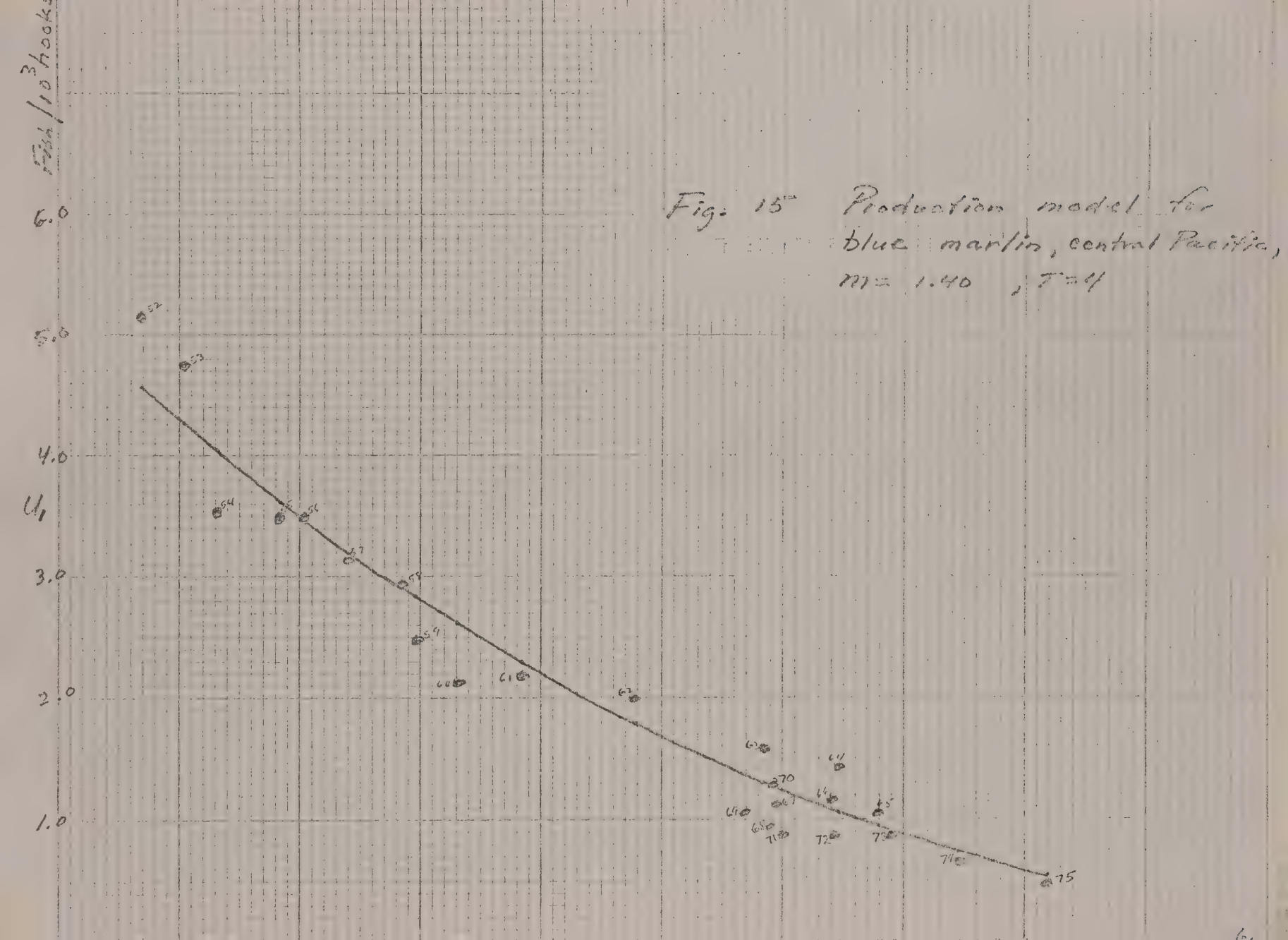

Fig. 15 Production model for blue marlin, central Pacific, $m = 1.40$, $F = 1$

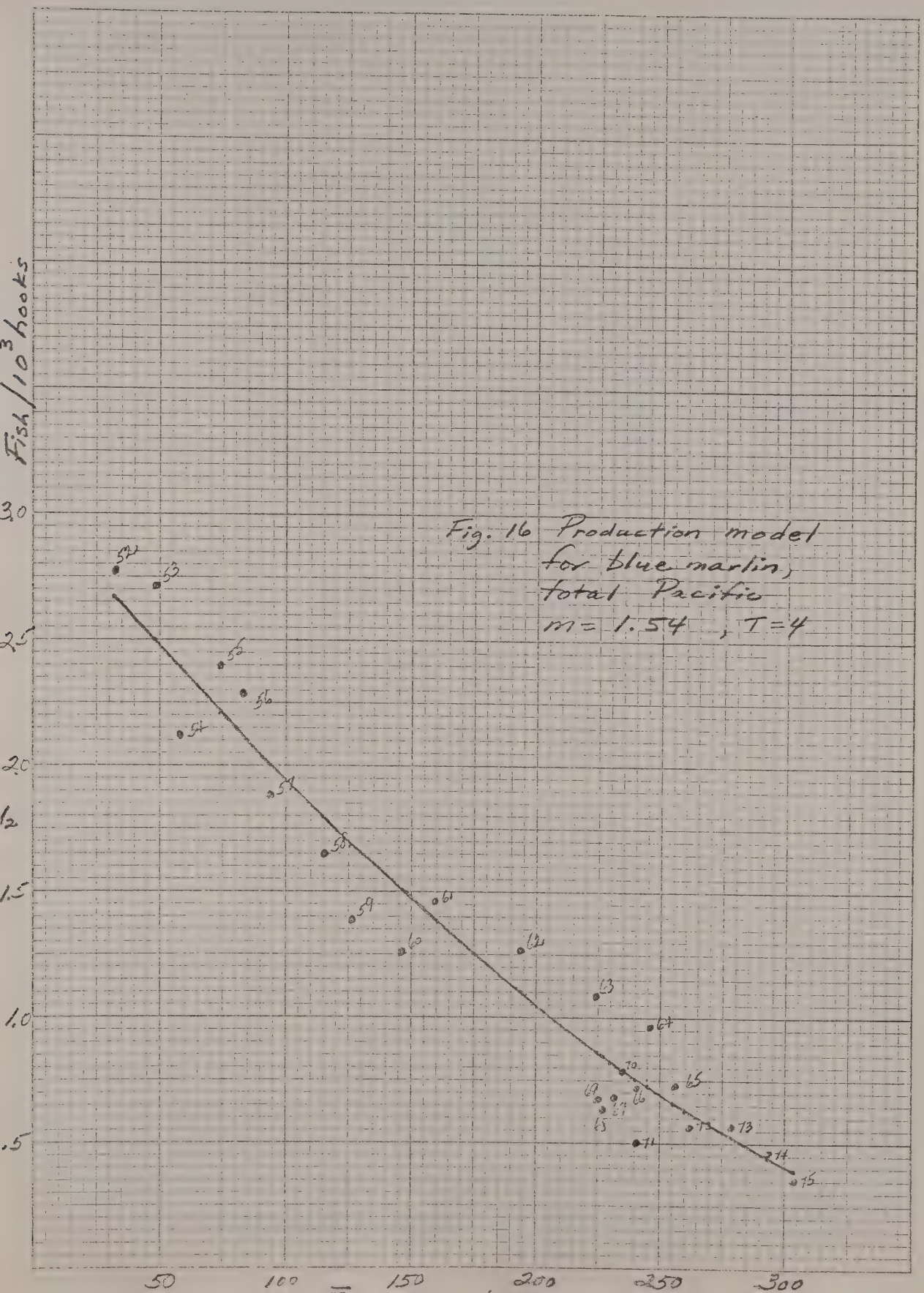

Fig. 16 Production model for blue marlin, total Pacific
$m = 1.54$, $T = 4$

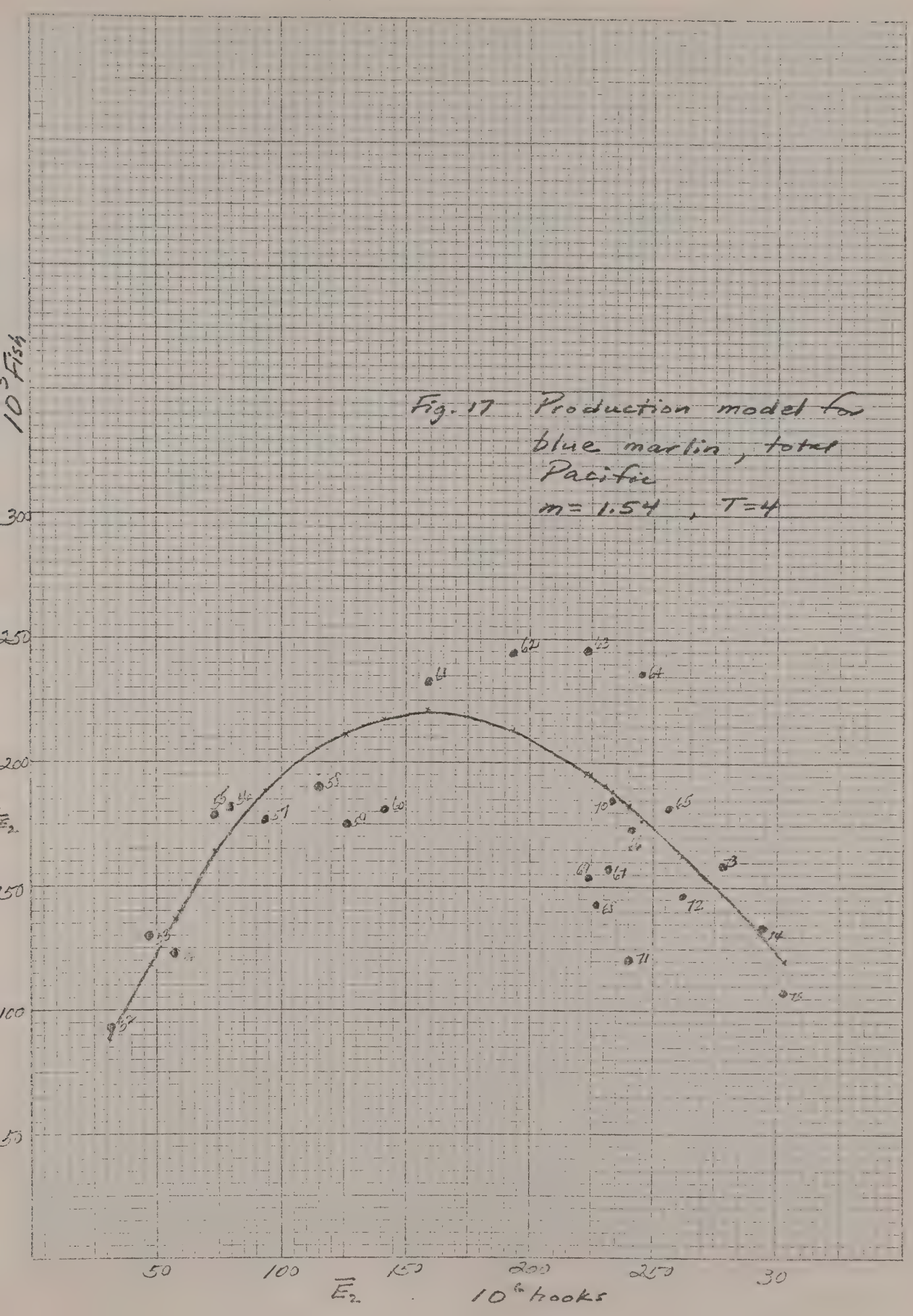
Fig. 17 Production model for blue marlin, total Pacific
m = 1.54 , T = 4
10^3 Fish
300
250
200
150
100
50
50
100
150
200
250
300
E_2
10^6 hooks

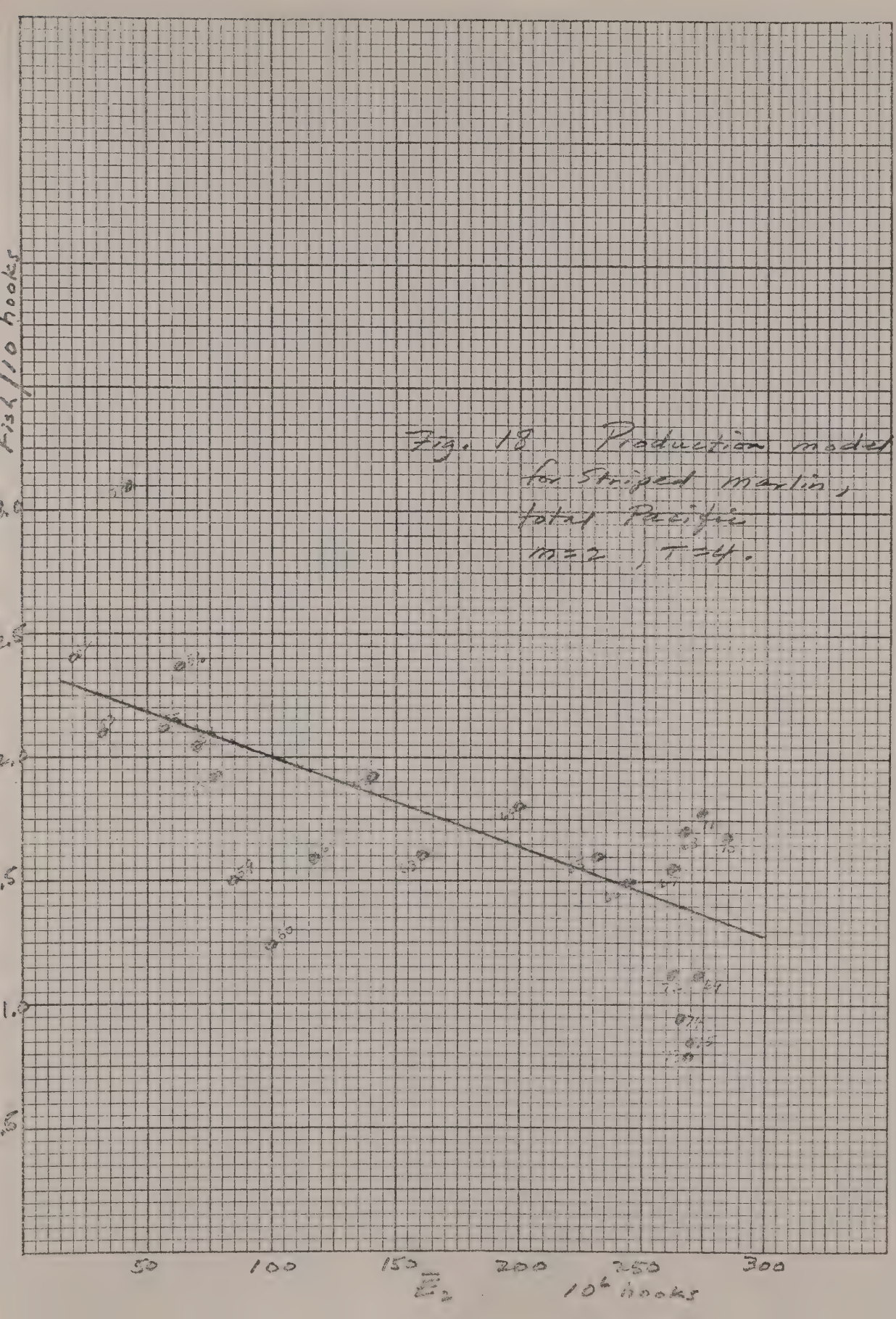
Fig. 18 Production model for striped marlin, total Pacific m=2, T=4.
Fish/10 hooks
50
100
150
200
250
300
E_2 10^4 hooks

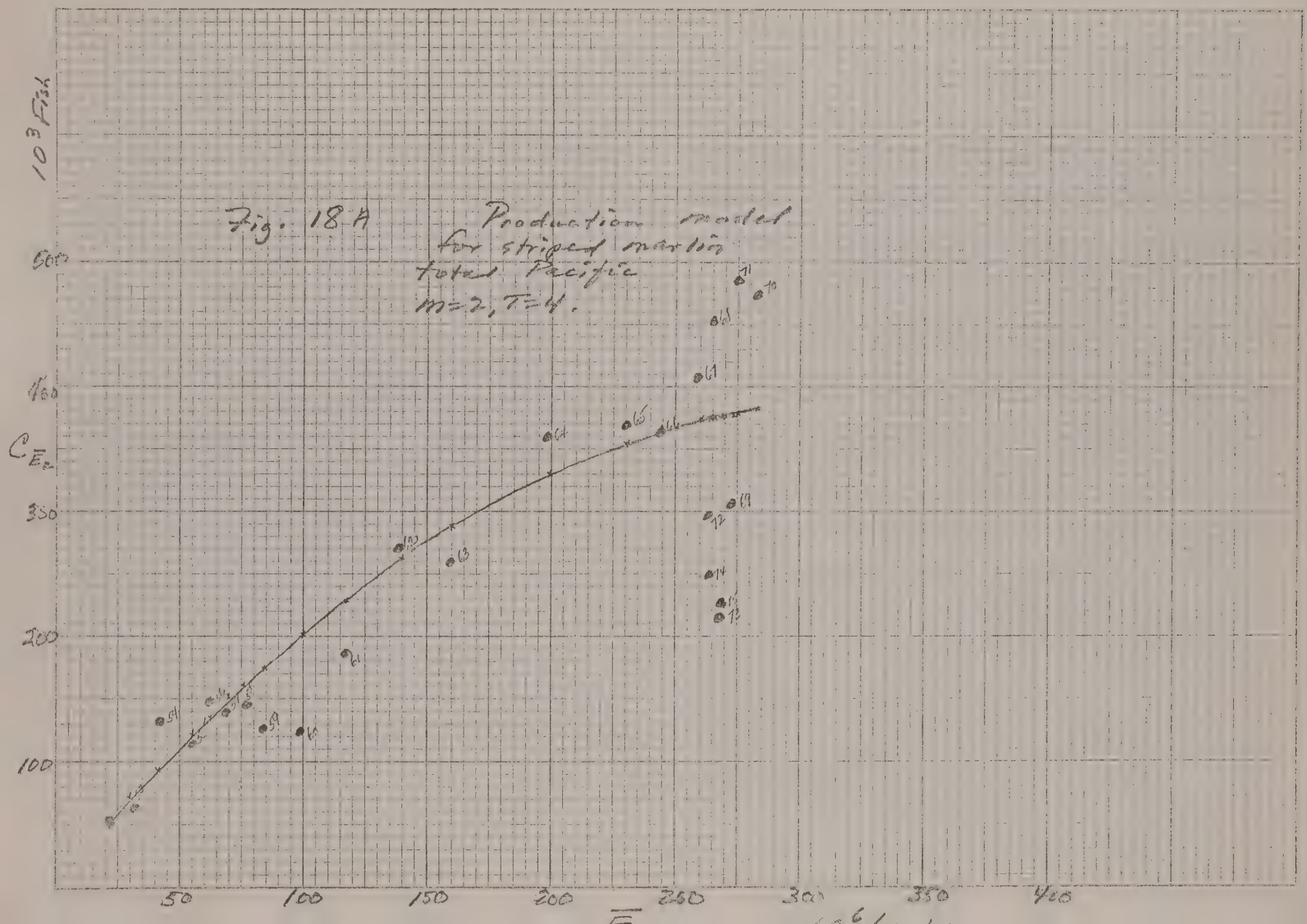
Fig. 18 A
Production model
for striped marlin
total Pacific
m=2, T=4.
$10^3 F_{3,4}$
$C_{E_{3,4}}$
500
400
350
200
100
50
100
150
200
250
300
350
400

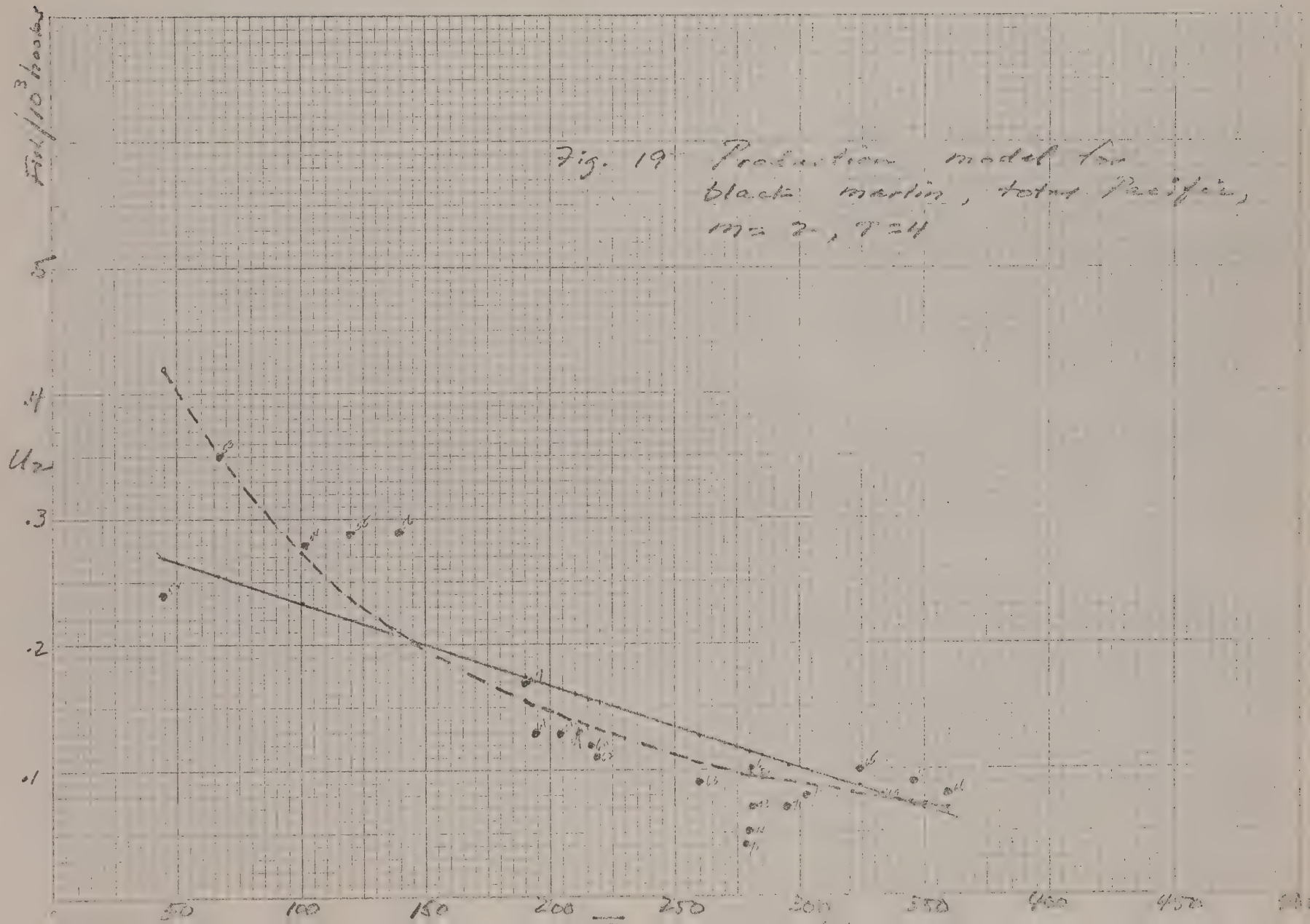

Fig. 19 Production model for black marlin, total Pacific, $m = 2$, $T = 4$

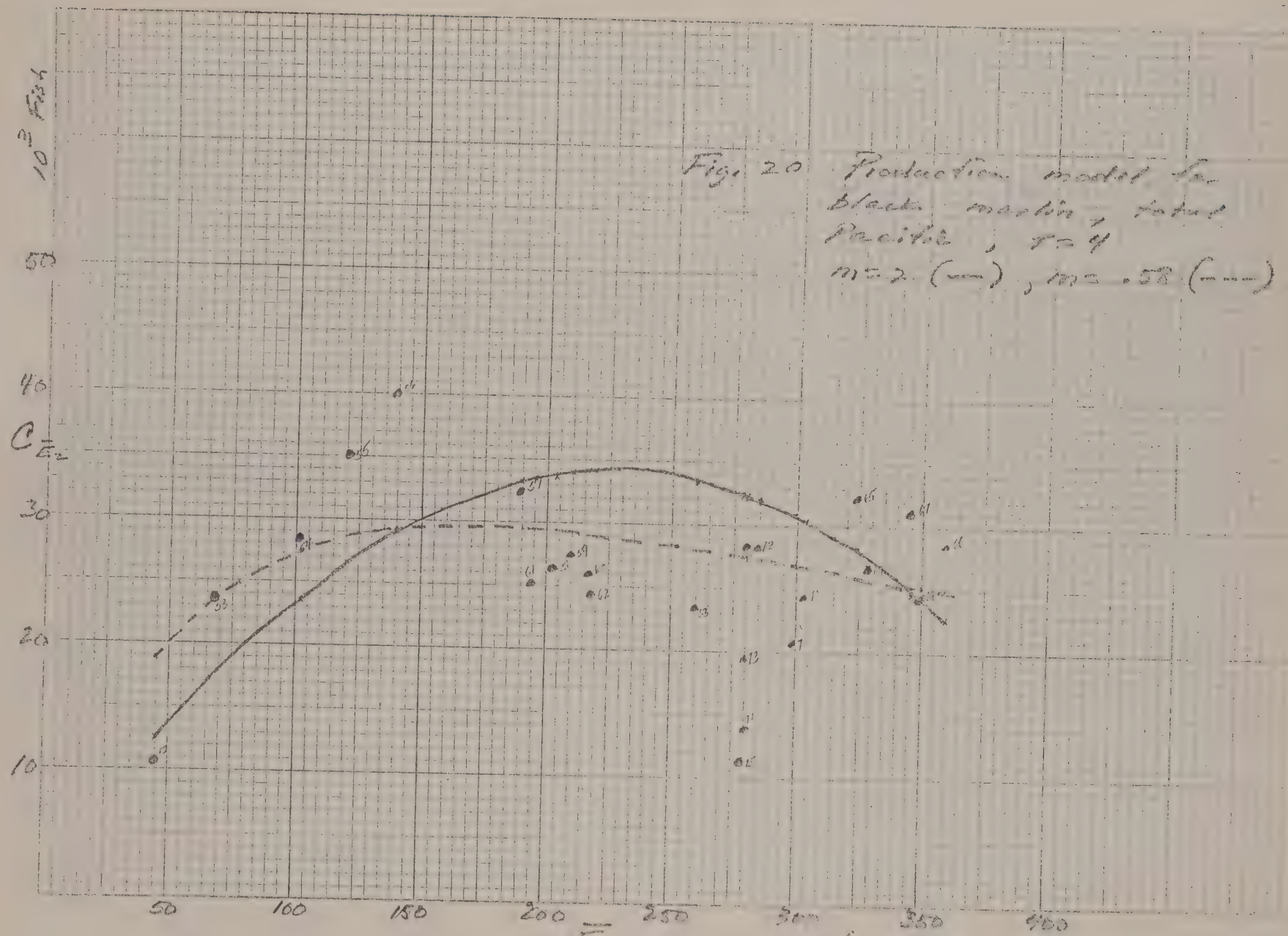

Fig. 20 Production model for black marking, Polaroid, $\gamma = \frac{1}{4}$
$n = 2$ (—), $n = .58$ (- - -)

KEUFFEL & ESSER CO.

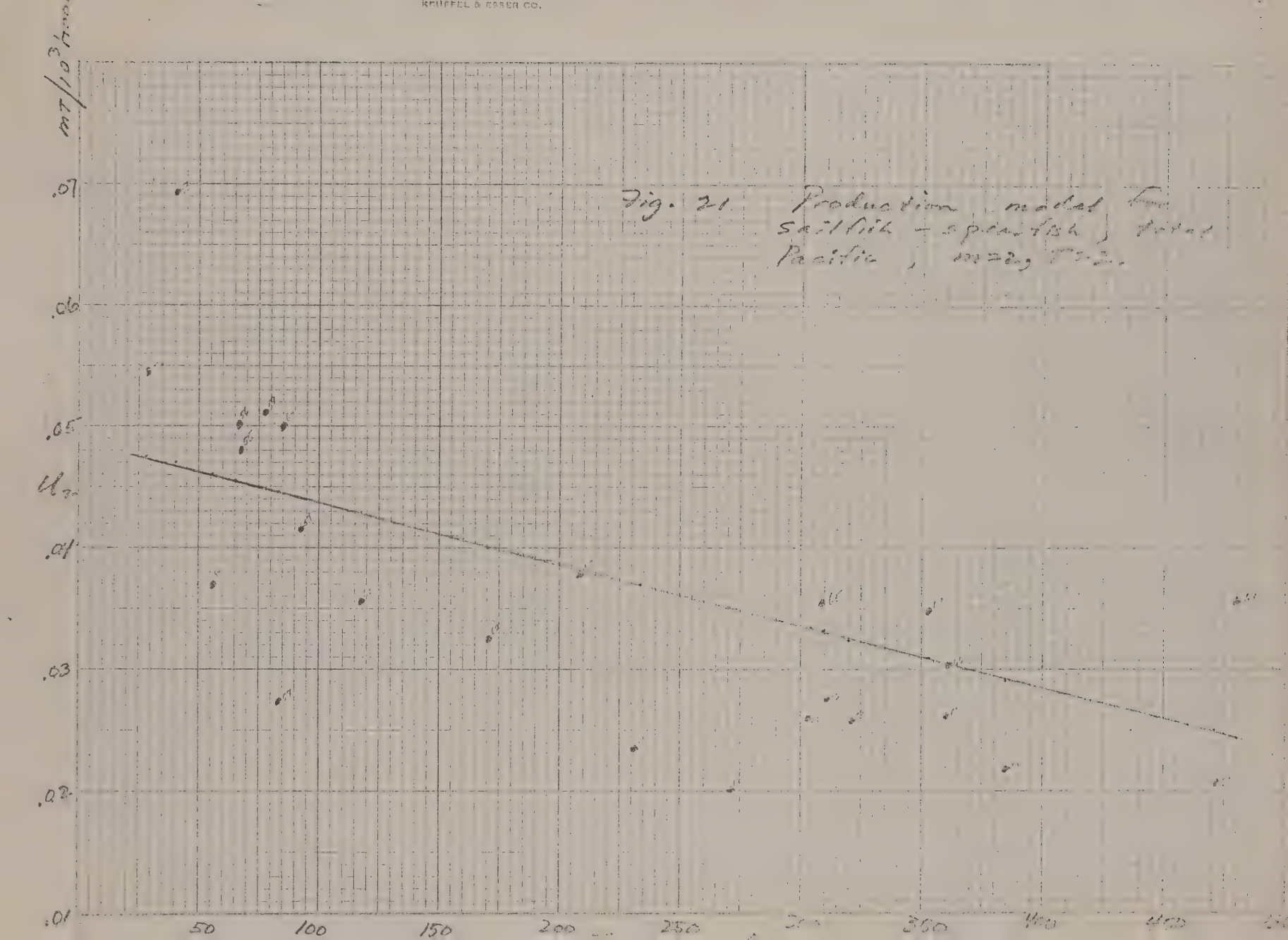

Fig. 21 Production modified for skillfish + spearfish) Total Pacific, 1929-32.

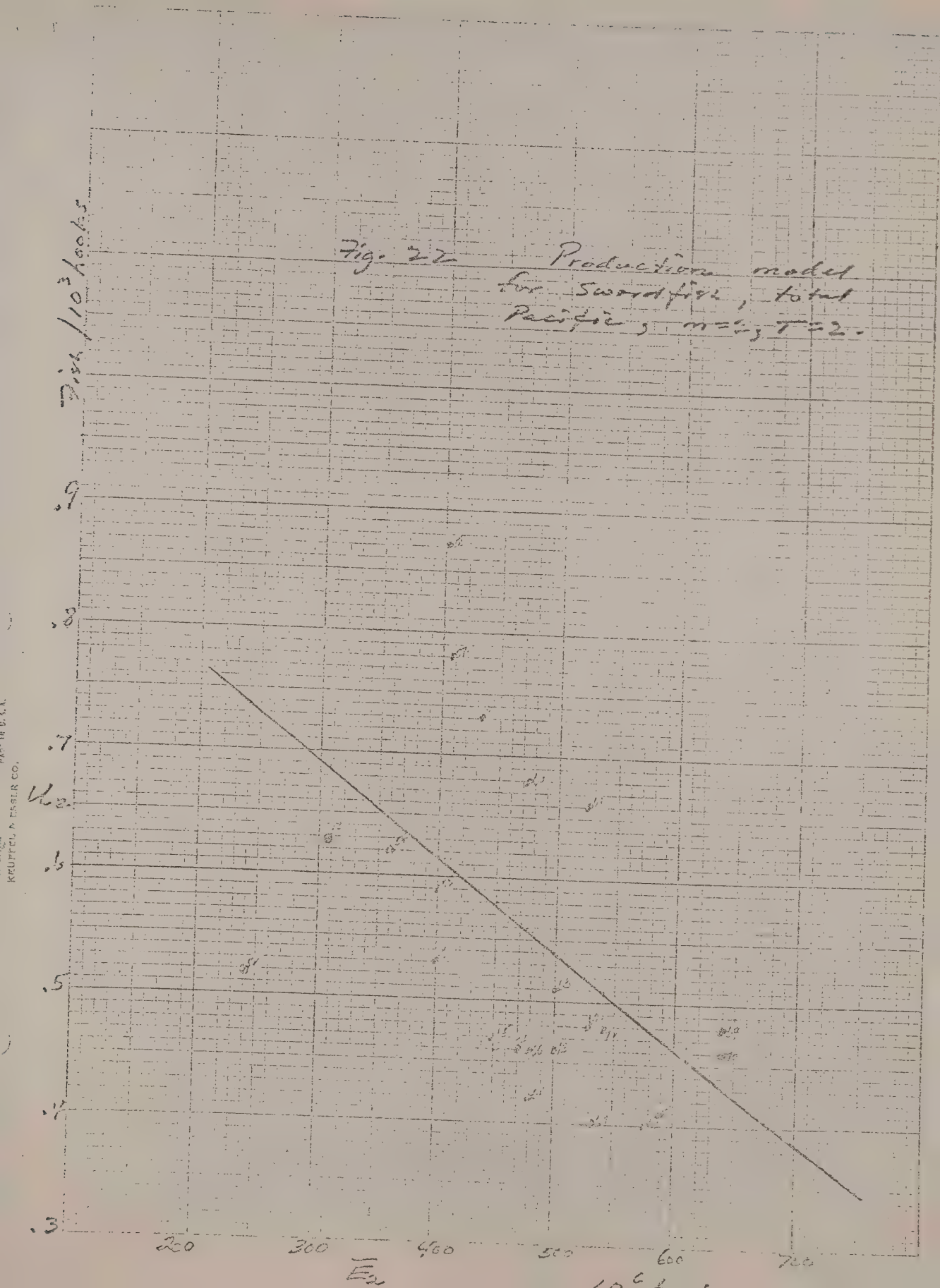

Fig. 22 Production model for swordfish, total Pacific; m=3, T=2.

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OVERVIEW OF FISHERIES FOR BILLFISHES IN HAWAII

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BILLFISH STOCK ASSESSMENT WORKSHOP

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OVERVIEW OF FISHERIES FOR BILLFISHES IN HAWAII

Introduction

The species of billfishes caught in Hawaii are blue marlin, Makaira nigricans, striped marlin, Tetrapturus audax, black marlin, Makaira indica, sailfish, Istiophorus platypterus, shortbill spearfish, Tetrapturus angustirostris, and swordfish, Xiphias gladius. Striped marlin and blue marlin are by far the most commonly caught species. The major methods by which billfishes are caught are commercial longliners and recreational trollers. This paper is a review of the catch statistics and the deductions that may be made from certain analyses of these statistics.

Description of Data and Data Sources

All licensed commercial fishermen in Hawaii are required to file
Fig. 1 a monthly catch report on a standard form (Figure 1) with the Division of Fish and Game of the State of Hawaii (HFG). Information requested at the top of the form is for the purpose of identifying the licensee and the fishing boat. Other information requested are: day of fishing, area fished, type of fishing gear used, species caught number caught, pounds caught, pounds sold, value of pounds sold, and port of landing. Area of fishing refers to the statistical areas as defined by HFG
Fig. 2 (Figure 2). For this study the HFG areas were grouped into larger units which are also shown in Figure 2. These were called windward Kauai, leeward Kauai, windward Oahu, leeward Oahu, windward Maui, leeward Maui, windward Hawaii, leeward Hawaii, north windward, north leeward, south windward, and south leeward.

HFG data dating back to 1948 are available but only data from 1966 through 1975 are in a format suitable for detailed analysis. HFG data were examined for long-term trends in the annual catch, major fishing areas, and the relative contributions to the total catch by trolling and longlining for each of the billfish species.

Another source of data on billfish catches is the auction records of the United Fishing Agency. The auction records have data on the date of sale, species and weight of each fish, sale price, and seller (name of fisherman or boat). The records do not designate the method of capture. Familiarity with the names of the longline boats, however, make it possible to identify the billfish caught by them. The other billfish listed on the records were for the most part probably caught by recreational fishermen trolling. A few of them may have been caught by incidental trolling by commercial skipjack tuna fishermen or by handlines. The data from the United Fishing Agency from 1958 through 1963 and from 1968 through 1975 were examined to determine seasons and average weight trends. Records for the period 1964-67 were missing.

Data on the catch of recreational fisheries have not been systematically collected by any agency. Although a major effort was made to collect recreational data from varied sources such as fishing clubs and charter boat skippers, in the end the only data suitable for analyses were the records of the Kona Activities Center and the Honolulu Laboratory of the National Marine Fisheries Service. The Kona Activities Center which books 40%-60% of the charter business in the Kona area provided records which listed boat-days of fishing, date of capture,

species, and weight of fish for the period of January 1974-November 1977. The Honolulu Laboratory's records contained similar information for the annual Hawaiian International Billfish Tournament which is held in Kailua-Kona. The data on recreational fishing treated in this study is thus limited to the area of leeward Hawaii. These data provided information on monthly catch per unit effort from which the seasonality of blue marlin, striped marlin, black marlin, and shortbill spearfish were determined.

In June of 1971 a ban on the sale of blue marlin, black marlin, and swordfish was imposed because of new regulations on allowable levels of mercury in fish. The ban resulted in fishermen not reporting their catches of these species. In May of 1973 the ban was eased to permit the sale of individuals of these species that weighed less than 136 kg. The data from HFG and the United Fishing Agency from mid-1971 onward therefore, do not truly reflect the numbers of these species caught nor the weights of all the fish caught.

The Fisheries

Seventeen longline boats are currently active in the State of Hawaii. Two of these are based on Hawaii, the rest on Oahu. Of the 15 on Oahu 3 are newer boats which are larger, have greater range, and can fish more hooks than the older "traditional" boats. The old boats fish 120-180 hooks per set. The new boats fish about 600 hooks per set. In 1976 the longline boat averaged 147 fishing days a year.

The other major billfish catchers are the recreational trollers. The number of boats engaged in this activity is open to conjecture. A summary of boats registered with the Division of Water Transportation Facilities shows about 5,400 boats with the capability of deepwater fishing. A survey of boat owners in the Kona area (unpublished report of Research Associates) indicated that 71% of them used their boats for deepwater fishing. If that rate is projected to the 5,400 boats, 3,800 boats are used for deepwater fishing. Because of the exceptional fishing conditions in Kona, the percentage of Kona boat owners fishing may be too high to apply to the rest of the State. Making an adjustment for that, I think a "ballpark" guess of 3,200 boats in deep-sea recreational fishing is reasonable.

The Kona boat owners average 69 days of fishing a year. That average is also probably higher than the average for the entire State. If one guesses that 50-60 days a year is reasonable, the total fishing days would be 160,000-190,000 days a year.

A professional component in recreational fishing is the corp of charter boats. There are approximately 65 charter boats available for hire in Hawaii. Projection of the 133 charter days per year experienced by the charter boats in Kona (Research Associates, unpublished) to the entire fleet would add 8,600 boat days of fishing.

Besides the longliners and recreational trollers commercial fishermen in other fisheries catch billfish incidentally. Their billfish catches are rare, however, and will not be noted again in this overview.

Striped Marlin

Striped marlin is the most commonly caught billfish in Hawaii. This has not always been the case. Prior to 1962 blue marlin catches usually exceeded striped marlin catches in weight. In 1950 the catch
Fig. 3 of striped marlin reached a peak of 260 metric tons (MT) (Figure 3). In 1964 it reached another peak of 228 MT after a low of 93 MT in 1954. The catch declined from 156 MT in 1970 to 87 MT in 1971, the first year of the mercury scare. It has since reached a low of 64 MT in 1973 and has risen to 94 MT in 1975.

Before the last decade striped marlin was caught almost entirely by longlines. Since 1968 the amount caught by trolling has increased
Fig. 4 steadily (Figure 4). The percentage of the striped marlin catch caught by longlines has decreased from 99% in that year to 32% in 1975. The most productive area by far for striped marlin was leeward Oahu. Leeward Maui and windward Hawaii yielded moderate amounts of striped marlin. Noticeable amounts also came from leeward Hawaii, windward Maui, windward Oahu, windward Kauai, and south windward.

The seasonality of striped marlin in Hawaii is shown by a plot of
Fig. 5 the monthly longline catch summed over 14 yr (Figure 5). The highest catches occur in December. This is preceded by an extreme low in August with increasing catches in the intervening months. There appears to be a dip in catches in January which rises to a moderate plateau which extends from February to May. The catches drop from May to the August low. The monthly CPUE of striped marlin in the Kona recreational fishery averaged over the last 4 yr shows the low to be centered in

October, a couple of months later than the low of the longline fishery. The peak month is June in the Kona fishery. Where the longline season for striped marlin shows a rapid rise from its low point to its high point and a gradual decrease to its low point, the Kona season shows a rapid decline from its peak to its low and a gradual increase.

The frequency distribution of the weights of striped marlin from
Fig. 6 the longline fishery (Yoshida 1974) is reproduced here (Figure 6) to illustrate the range of sizes. The mean weight of striped marlin caught by trolling was decidedly greater than those caught on the longlines
Fig. 7 (Figure 7). In the period 1958-63 the average difference in mean weight was 10.7 kg. For the period 1968-75 the difference had been reduced to 2.8 kg on the average. In 1969 and 1971 the longline caught fish were in fact slightly heavier than the troll caught ones. A prominent feature of Figure 6 is the decrease in mean weights. The striped marlin caught by trolling between 1958 and 1963 showed the greatest decrease from 56.6 to 35.9 kg. This amounts to a decrease of 4.1 kg per year. In 1968 when the data is resumed after the years of the data gap the mean weight of the troll caught fish had fallen to 32.2 kg. In the ensuing 7 yr within which there were up and down fluctuations the mean weight showed a net gain of 3.6 kg. The longline caught fish showed a less drastic decrease in mean weight. From 1958 to 1963 there was a 4.5 kg decrease in mean weight; in the 5 yr of the data gap there was no decrease; and in the last 7 yr ending with 1975 there was a 1.7 kg decrease.

Blue Marlin

The catch of blue marlin reached a high of 366 MT in 1954, and except for 3 yr, had declined until 1972 (Figure 8). The catch was 25 MT in 1974 as the result of an average 19 MT per year decrease over a period of 18 yr. The drop from 120 to 25 MT during 1970-72 was the result of the ban on the sale of blue marlin.

Fig. 8

The relative contributions of the trollers and the longliners to the total catch is presented in Figure 9. The trollers have been catching an increasing percentage of the total catch since 1968. By 1970 the troll catch had exceeded the longline catch. After that the data is meaningless because it is obvious that the longliners did not report their blue marlin catches, as in 1972, or only reported partially.

Fig. 9

The lion's share of the troll caught blue marlin came from leeward Hawaii. Leeward Oahu was second in the number of blue marlin caught by trolling. Third was leeward Maui. That the leeward areas are on top of the list probably reflects the preference of these areas by the recreational fishermen for the pursuance of their sport rather than a preference of the blue marlin for these areas. The leeward and windward areas of Hawaii were the best blue marlin areas for longline fishing. Leeward Oahu and the south windward area were next best. Longliners also caught blue marlin in lesser amounts in windward Oahu and the windward and leeward areas of Maui and Kauai.

The average monthly catches of blue marlin on the longlines (Figure
Fig. 10 10) show a season reaching a climax in July and August. The first half of the year shows a rise from a January low and the second half shows a drop to the January low. The average monthly CPUE of the Kona recreational fishery shows a high dome occurring in August and September and a depression from March to May. The blue marlin season in the Kona fishery appears to be later than that for the longline fishery. The seasonal low occurs 2 mo later and the seasonal high occurs 1 mo later. This results in the Kona fishery having a shorter rise period and a longer decline period than the longline fishery.

The mean weight of blue marlin caught by trolling for the years 1958-63 was smaller than that of their longline caught counterparts
Fig. 11 (Figure 11). The average yearly difference in size was 12.3 kg. In the same years the mean size of the longline caught blue marlins exhibited wide fluctuations and ended at 111.5 kg for a net decrease of 29.0 kg. The plot of the mean weight of the troll caught fish for the same period was W-shaped that started at 117 kg and ended at 116.3 kg. For the 3 yr after the data gap the fish caught by both methods were about the same size, both fluctuating around 90 kg.

Fig. 12 The weight-frequency distribution of blue marlin (Figure 12) reproduced from Yoshida (1974) shows clearly the differences in sizes and the distribution of sizes between the males and females. That troll caught blue marlin were smaller than those caught on the longline reflects the predominance of males in the recreational fishery. The male to female ratio in the Kona fishery is seldom less than 2:1 and

may be as high as 8:1. The weight-frequency distribution of blue marlin caught in Kona exhibited a dominant mode in the 70-80 kg weight class and a decelerating decline to 430 kg.

Black Marlin

Historically the catch of black marlin in Hawaii has always been small compared to the catches of the blue marlin and striped marlin. In the last 30 yr the best catch of black marlin was 12.3 MT for 1958. Since then the yearly catch has declined precipitously with large up and down fluctuations from year to year (Figure 13). The catch in 1975 added up to half a metric ton.

Fig. 13

From 1967 through 1970, 90% or more of the black marlin were caught with longline gear (Figure 14). Since 1971 the troll catch has exceeded the longline catch in every year but one. The number caught per year from 1972 through 1975, however, has not been more than nine individuals.

Fig. 14

The areas around Hawaii, especially the windward area, was best for black marlin. Almost all of the troll catches were made in leeward Hawaii. Longline catches of black marlin were also made in the leeward and windward sides of the other island areas and in the south windward area.

The longline catch summed over 14 yr and classified by months (Figure 15) indicates that October is the month with the highest catch and January the lowest. The catch in October is only 4 times that of January so the black marlin does not appear to be very seasonal. The

Fig. 15

monthly catch rate of the Kona recreational fishery exhibits a peak in April and a low during the winter months. The reliability of the catch rates is in question, however, because they were calculated from very skimpy data.

Swordfish

With few exceptions all of the swordfish caught in Hawaii were caught on longline gear. From 1948 until the present the annual catch of this species has been on a decline which was interrupted with one moderate rise (Figure 16). The 45.5 MT catch of 1948 dropped to 5.1 MT in 1954, an average drop of 6.7 MT per year. In 1955 the catch rose to 17.1 MT from which point it has gone down to 5.4 MT in 1970, the last year before the mercury crisis. Since then the recorded catch has been negligible.

Fig. 16

Windward Hawaii was once the best area for swordfish, but the catch from that area has fallen steadily from 4 MT in 1966 to 0.4 MT in 1970. Another outstanding area was leeward Oahu where 3.1 MT were caught in 1970. Other areas in order of production were south windward, windward Maui, leeward Hawaii, windward Kauai, windward Oahu, leeward Maui, and leeward Kauai.

Sailfish

The annual catch of sailfish, like those of the billfishes mentioned so far, has fallen in the last 30 yr (Figure 17). Most of the decrease occurred between 1948 and 1952. In those 4 yr the sailfish catch plummeted from 79.1 to 9.8 MT. From 1954 to 1959 the

Fig. 17

annual catch maintained a level between 2 and 9 MT. In 1971 it went to a lower level of 0.5 MT which persisted through 1975.

Up until the annual sailfish catch had dropped to 0.5 MT, longline fishermen caught 96% or more of the catch. In the years 1973-75 the amount caught by trolling increase to 0.2 MT, slightly less than half of the total catch of that period.

The best sailfish areas were leeward Oahu, windward Hawaii, windward Maui, and south windward. Windward Oahu was slightly better than the others. Leeward Hawaii and leeward Maui were also relatively good areas.

In the analysis of monthly catches sailfish and shortbill spearfish data were combined. During the years 1959-63 inclusive the catch was predominantly sailfish. The data of those years were chosen to be examined for the seasonal nature of the sailfish. The monthly totals

Fig. 18 of those years (Figure 18) indicate a major high and low in April and August, respectively, and a secondary high and low in October and January, respectively.

Shortbill Spearfish

Fig. 19 The annual catch record of the shortbill spearfish (Figure 19) is the only one among the billfish species that does not exhibit a trend of decline. Neither does it show a trend of increase. It shows extreme fluctuations in the catch. The catch increased from zero in 1951 to 6.2 MT in 1954. The catch of the following year was 0.8 MT. The change in catch from 1968 to 1970 was even more extreme. It went from zero to

10.5 MT in yr. In 1971 the catch was 2.5 MT. From there it went up to 6.5 MT in 1974.

From 1966 to 1971, 99% of the shortbill spearfish catch was by longline. Since then the amount caught by trolling has increased steadily. By 1975 trolling accounted for 38% of the catch.

The best area for shortbill spearfish was definitely south windward. Leeward Oahu was also a very good area. Following those two areas in order of shortbill spearfish yields were: leeward Hawaii, windward Hawaii, leeward Maui, windward Maui, windward Kauai, leeward Kauai, and windward Oahu.

In determining the seasonality of sailfish there was a problem of dealing with data which were a combination of sailfish and shortbill spearfish data. The same problem naturally occurred in determining the seasonality of the shortbill spearfish. The solution was the same. Select those years in which the species of interest was clearly dominant in the catch. For the shortbill spearfish the dominant years were 1973-75 inclusive. February, March, and April were clearly the
Fig. 20 best months in the plot of monthly totals (Figure 20). May and June were transition months to the off season which occurred from July to November. The catch rose sharply in December followed by a dip in January. The mean monthly CPUE (1974-77) for shortbill spearfish in the Kona recreational fishery shows the same pattern with a month's delay.

Discussion

The longline catch for the five species for which monthly data were available all showed a dip in January. The lower number of fish caught in January is probably due to reduced fishing effort more than the unavailability of fish. For many reasons, which will not be listed here, January is a good month for longline fishermen to take a vacation.

Four species--striped marlin, blue marlin, shortbill spearfish, and sailfish--demonstrated marked seasons of availability. Data from the Kona recreational fishery available for the first three mentioned species showed comparable seasonal patterns for each of the species. An interesting feature of the Kona seasonal patterns is that they lagged the seasonal patterns of the longline caught fish by about a month in each case. Is the delay the result of migration? If so, with Kona being in the southeast corner of the Hawaiian fishing area, the fish must be moving southward or eastward or along some resultant course which is a combination of those directional components. The predilection of these species to move northward in the spring and southward in the fall conflicts with any lag of the Kona patterns occurring in the early half of the year. The bimodal nature of the sailfish season suggests that the sailfish may be passing the islands in one direction at first and in the opposite direction later. Data on the seasonal occurrence of this species in the Kona area would have been a means of verifying this. Unfortunately, Kona data from those years when sailfish were more common than now are not available.

The figure of 160,000-190,000 boat days as an estimate for the total recreational fishing effort was based on a few nebulous assumptions. From data obtained from charter boat skippers (Research Associates, unpublished report) the catch rate of 0.32 kg per boat day for striped marlin for 1976 was calculated. When this rate is divided into the 55 MT of striped marlin caught by trolling in 1976 the result is 171,000 boat days.

Perhaps the most important feature of the data presented in this overview is the drastic drop in catches of five of the six billfish species in Hawaii in the last 15-20 yr. Particularly if the fish caught here come from highly migratory populations, as is implied by their seasonal nature which is possibly lacking in the black marlin, it is important to determine whether the decreases were caused by environmental changes or population changes.

Literature Cited

YOSHIDA, H. O.

1974. Landings of billfishes in the Hawaiian longline fishery. In R. S. Shomura and F. Williams (editors), Proceedings of the International Billfish Symposium, Kailua-Kona, Hawaii, 9-12 August 1972, Part 2. Review and Contributed Papers, p. 297-301. U.S. Dep. Commer., Natl. Mar. Fish. Serv., Spec. Sci. Rep. Fish. 675.

DEPARTMENT OF LAND AND NATURAL RESOURCES

FISH CATCH REPORT

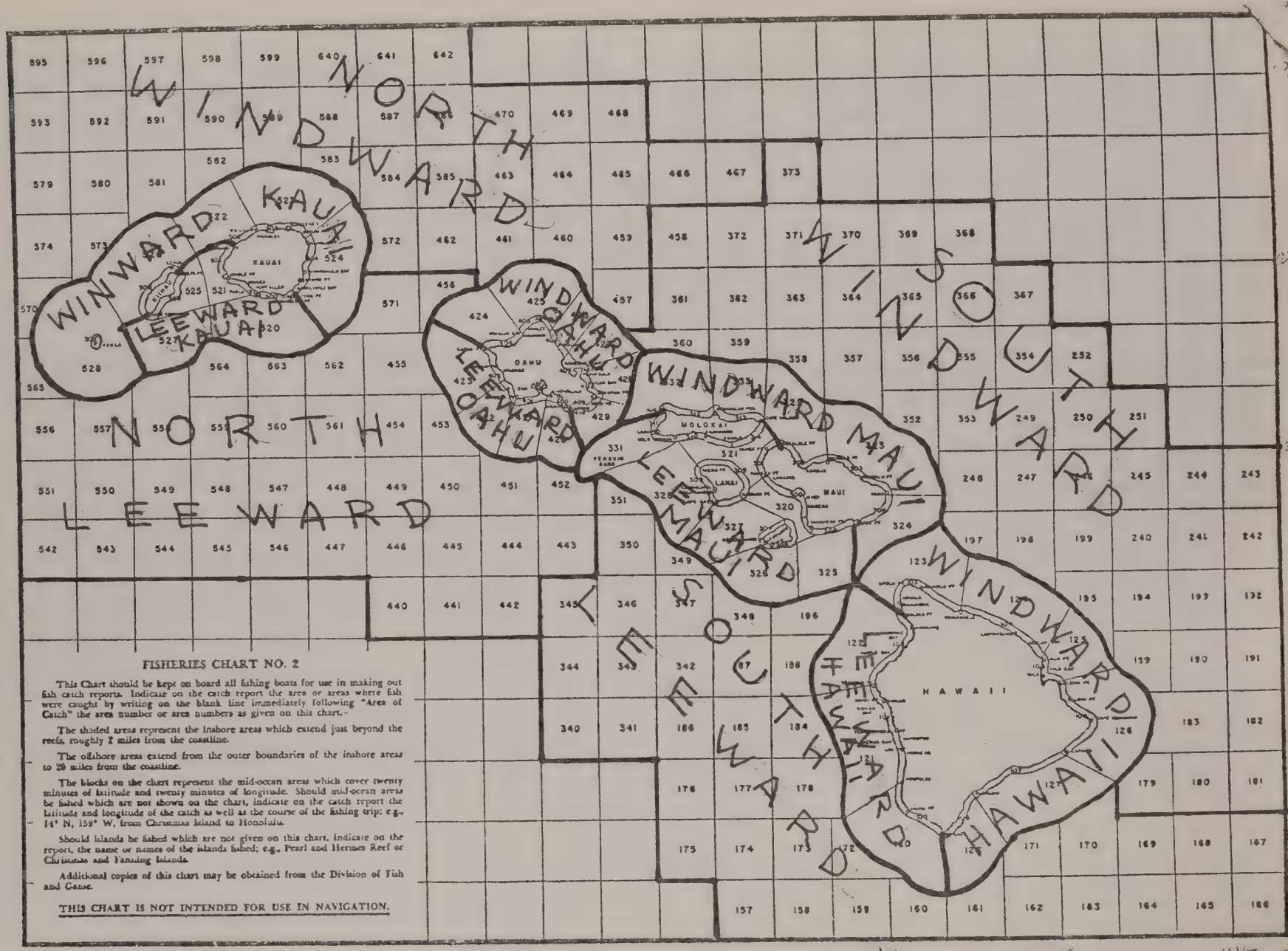
DIVISION OF FISH AND GAM
STATE OF HAWAII

1. Name of Licensee ..... 2. Commercial Fishing License No. .... 7 ☐ - ☐☐☐

3. Name of Boat ..... 4. HA No. H A - ☐☐☐☐ - ☐☐ 5. Federal No. ☐☐☐☐☐☐

6. Month Fished ..... 7. Year Fished–19 ☐☐

8. Day Fished	9. Area Fished	10. Type of Fishing Gear Used		11. Species Caught		12. No. Caught	13. Lbs. Caught	14. Lbs. Sold	15. Value of Lbs. Sold		16. Port of Landing



FISHERIES CHART NO. 2

This Chart should be kept on board all fishing boats for use in making out fish catch reports. Indicate on the catch report the area or areas where fish were caught by writing on the blank line immediately following "Area of Catch" the area number or area numbers as given on this chart.

The shaded areas represent the inshore areas which extend just beyond the reefs, roughly 2 miles from the coastline.

The offshore areas extend from the outer boundaries of the inshore areas to 20 miles from the coastline.

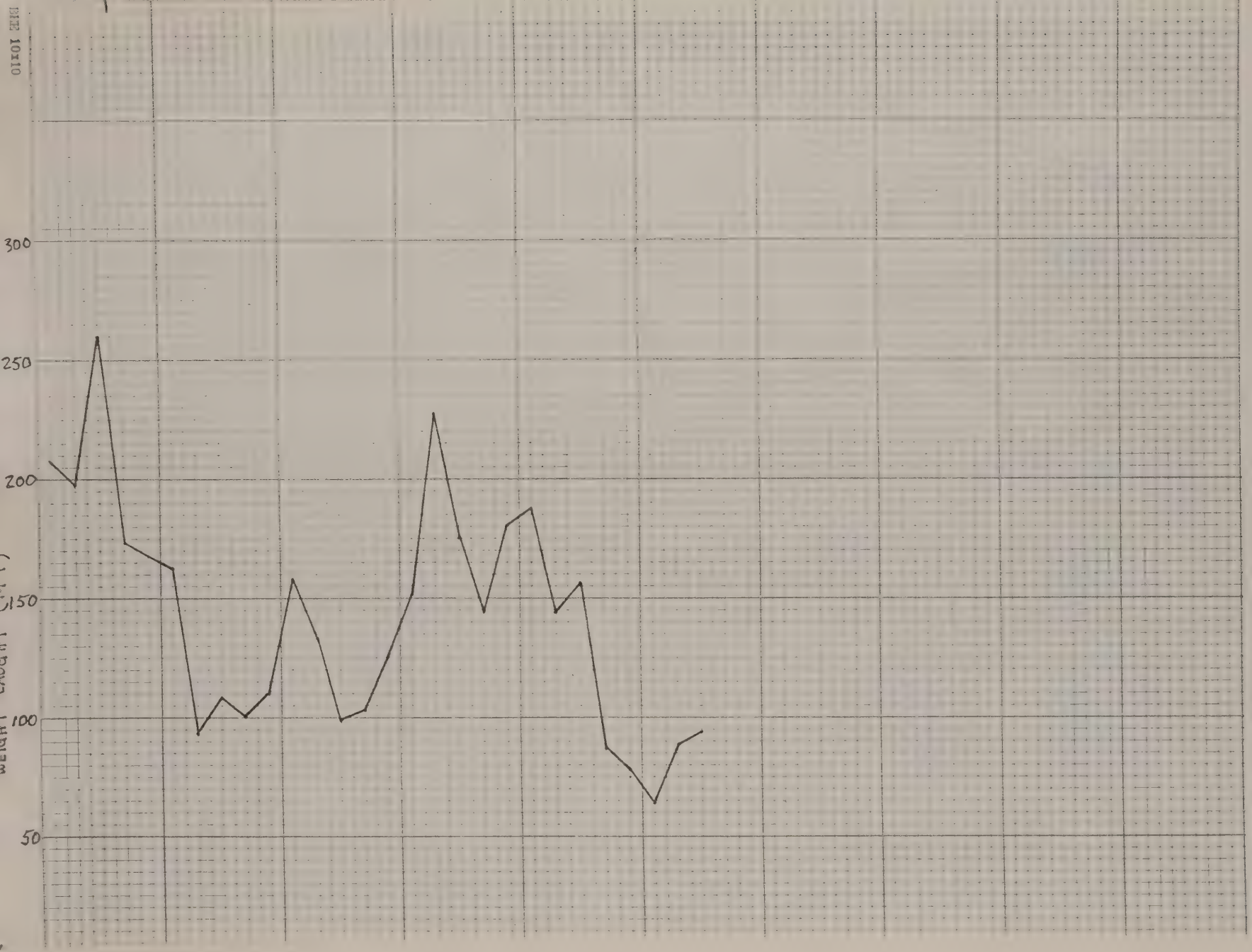
The blocks on the chart represent the mid-ocean areas which cover twenty minutes of latitude and twenty minutes of longitude. Should mid-ocean areas be fished which are not shown on the chart, indicate on the catch report the latitude and longitude of the catch as well as the course of the fishing trip; e.g., 14° N, 159° W, from Christmas Island to Honolulu.

Should islands be fished which are not given on this chart, indicate on the report, the name or names of the islands fished; e.g., Pearl and Hermes Reef or Christmas and Fanning Islands.

Additional copies of this chart may be obtained from the Division of Fish and Game.

THIS CHART IS NOT INTENDED FOR USE IN NAVIGATION.

159 156 155 154 FIG. 7


300
250
200
150
100
50

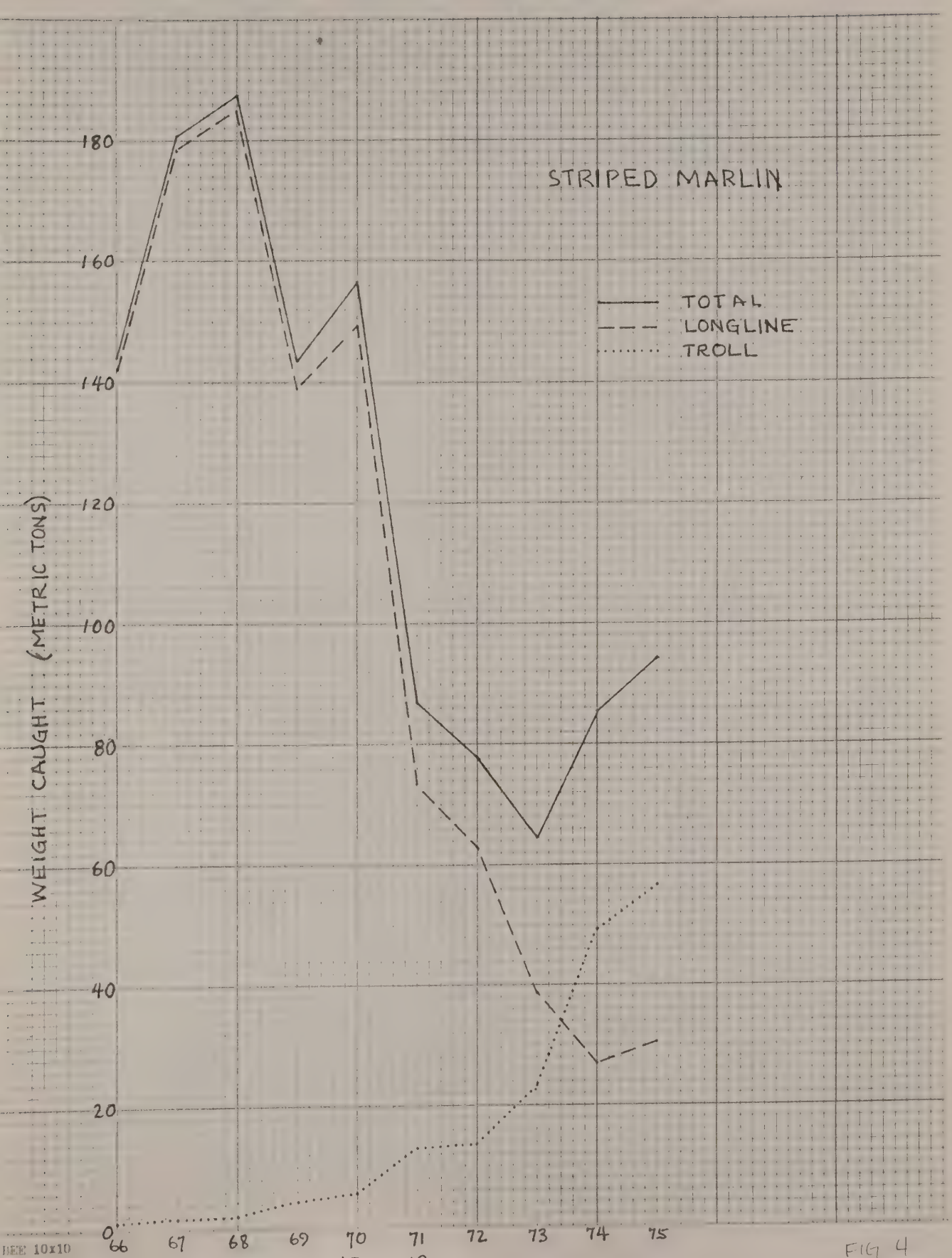
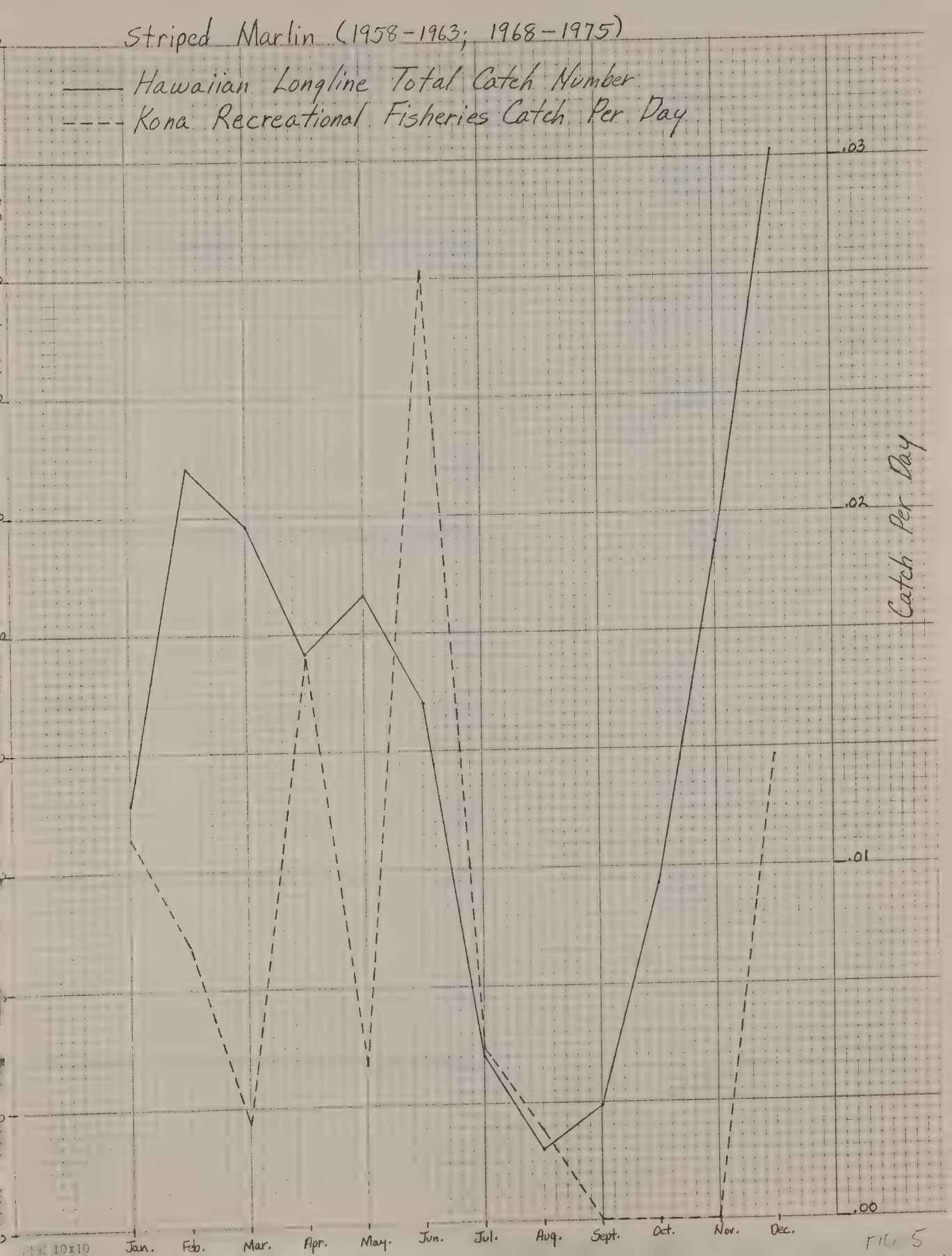

STRIPED MARLIN
TOTAL
LONGLINE
TROLL
WEIGHT CAUGHT (METRIC TONS)
180
160
140
120
100
80
60
40
20
0
66
67
68
69
70
71
72
73
74
75

FIG 4


Striped Marlin (1958-1963; 1968-1975)
Hawaiian Longline Total Catch Number
Kona Recreational Fisheries Catch Per Day
.03
.02
.01
.00
Catch Per Day
Jan.
Feb.
Mar.
Apr.
May.
Jun.
Jul.
Aug.
Sept.
Oct.
Nov.
Dec.
FIG 5

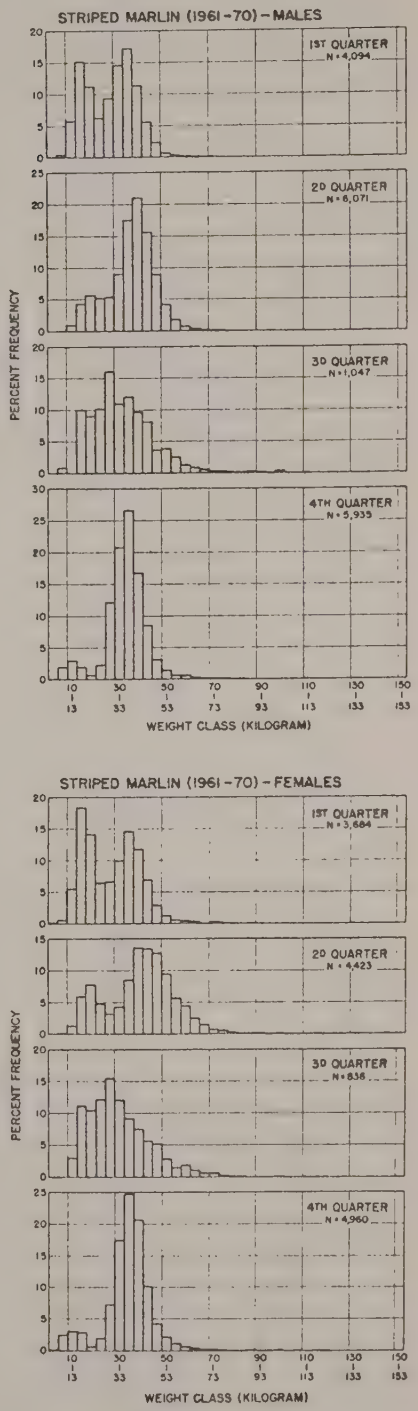
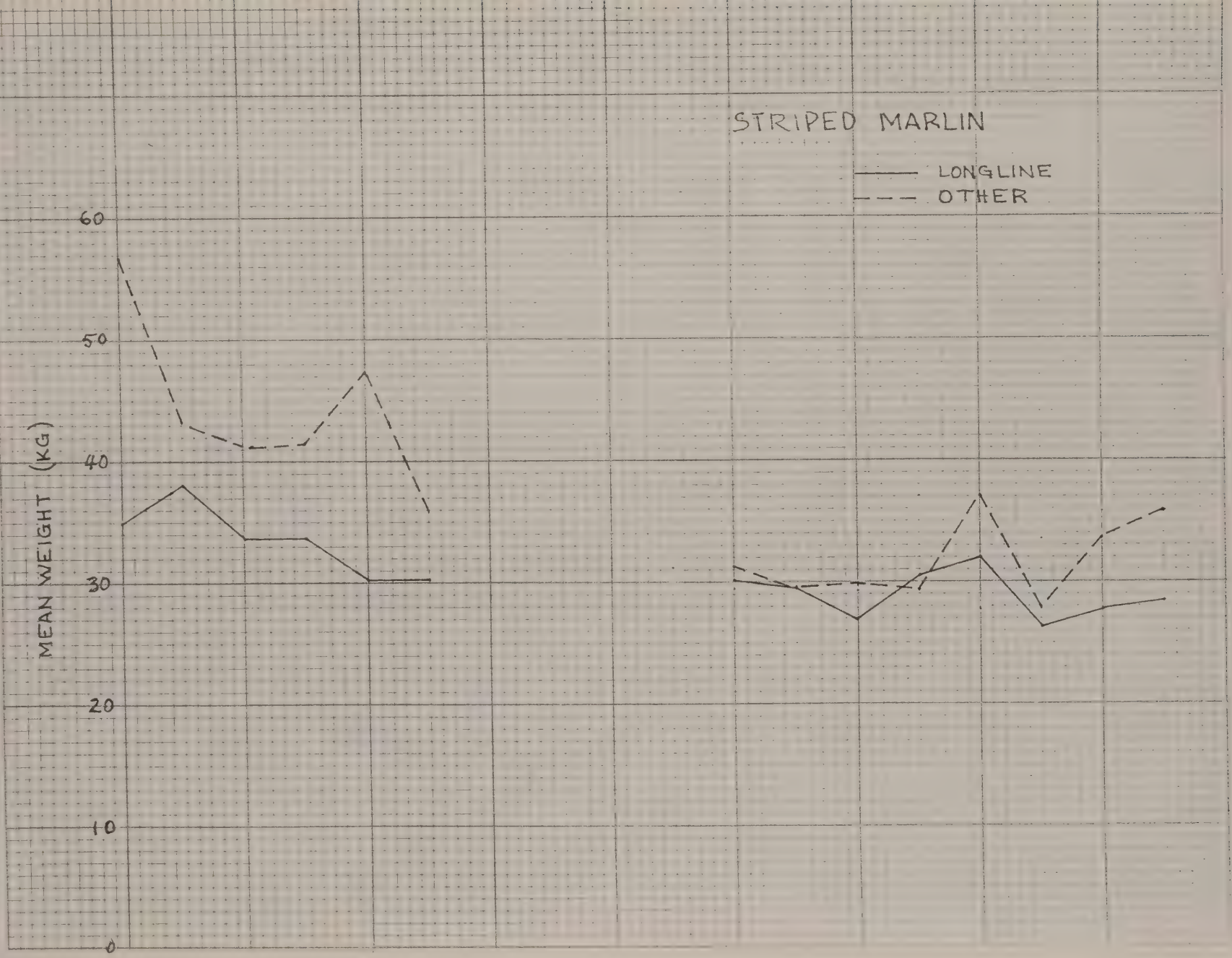
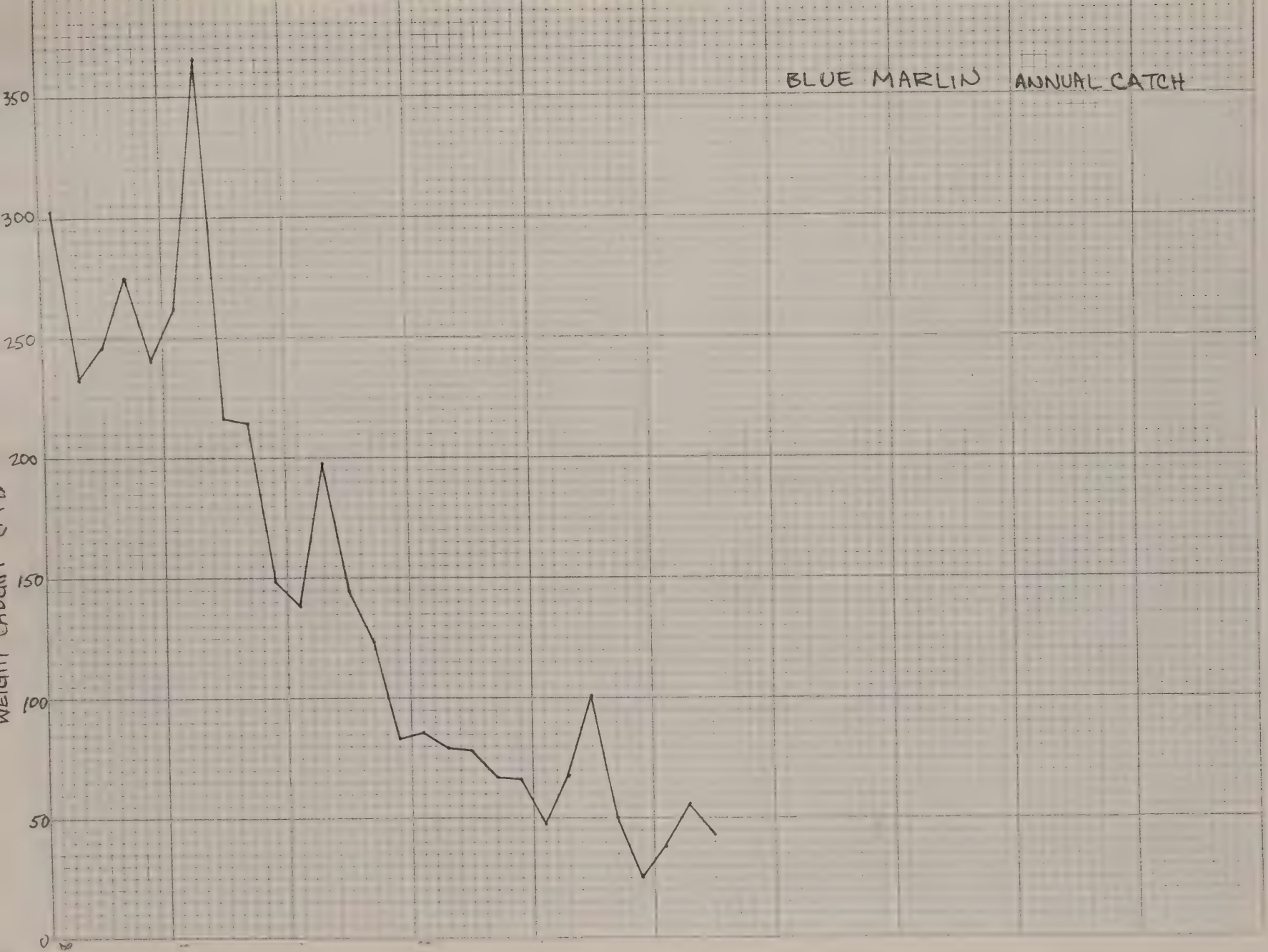


Figure 6.—Weight-frequency distribution of stripe marlin.


STRIPED MARLIN
LONGLINE
OTHER
MEAN WEIGHT (KG)
60
50
40
30
20
10
0


BLUE MARLIN ANNUAL CATCH
350
300
250
200
150
100
50
0

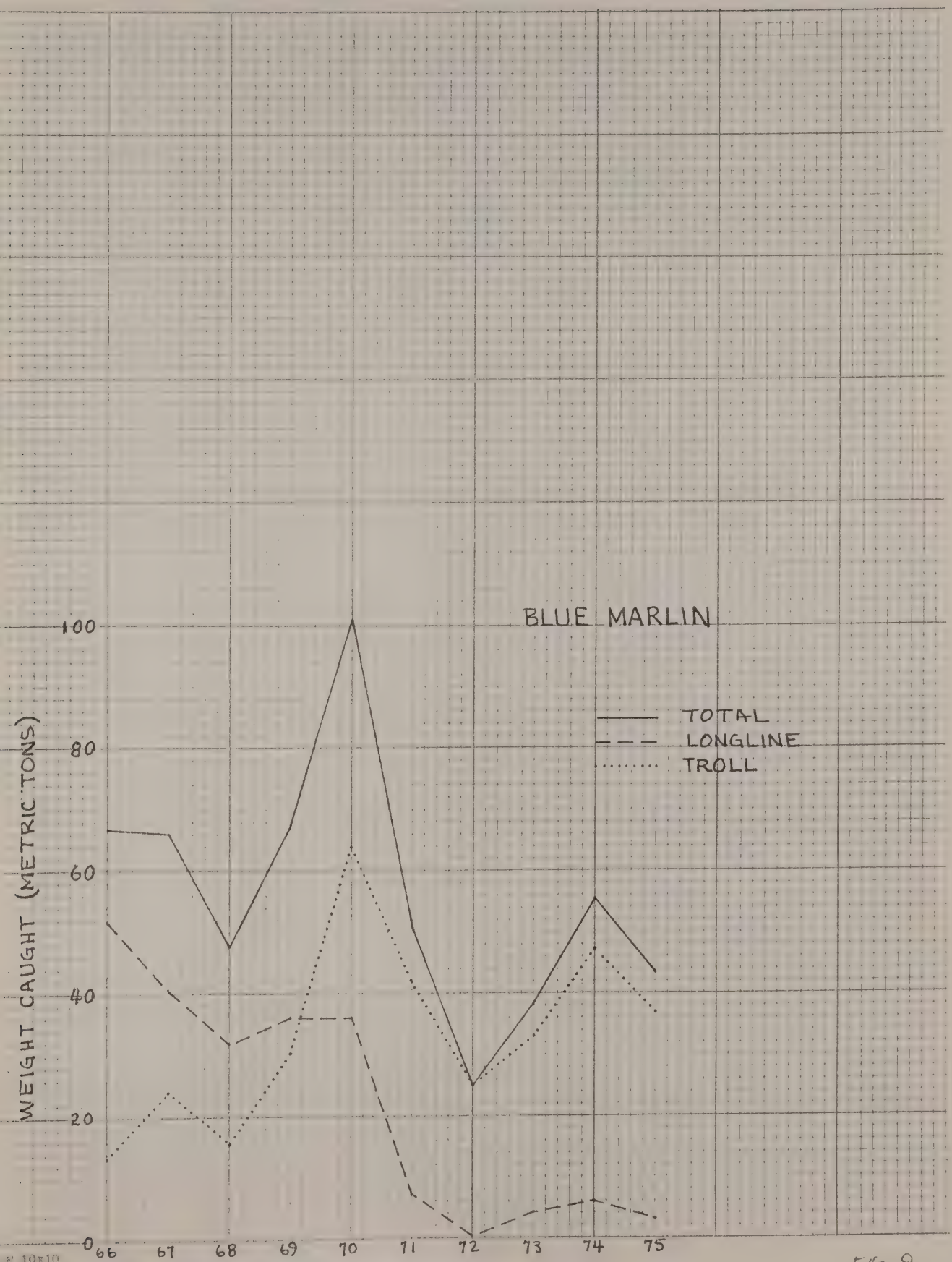

BLUE MARLIN
TOTAL
LONGLINE
TROLL
WEIGHT CAUGHT (METRIC TONS)
100
80
60
40
20
0
66
67
68
69
70
71
72
73
74
75

FIG. 9

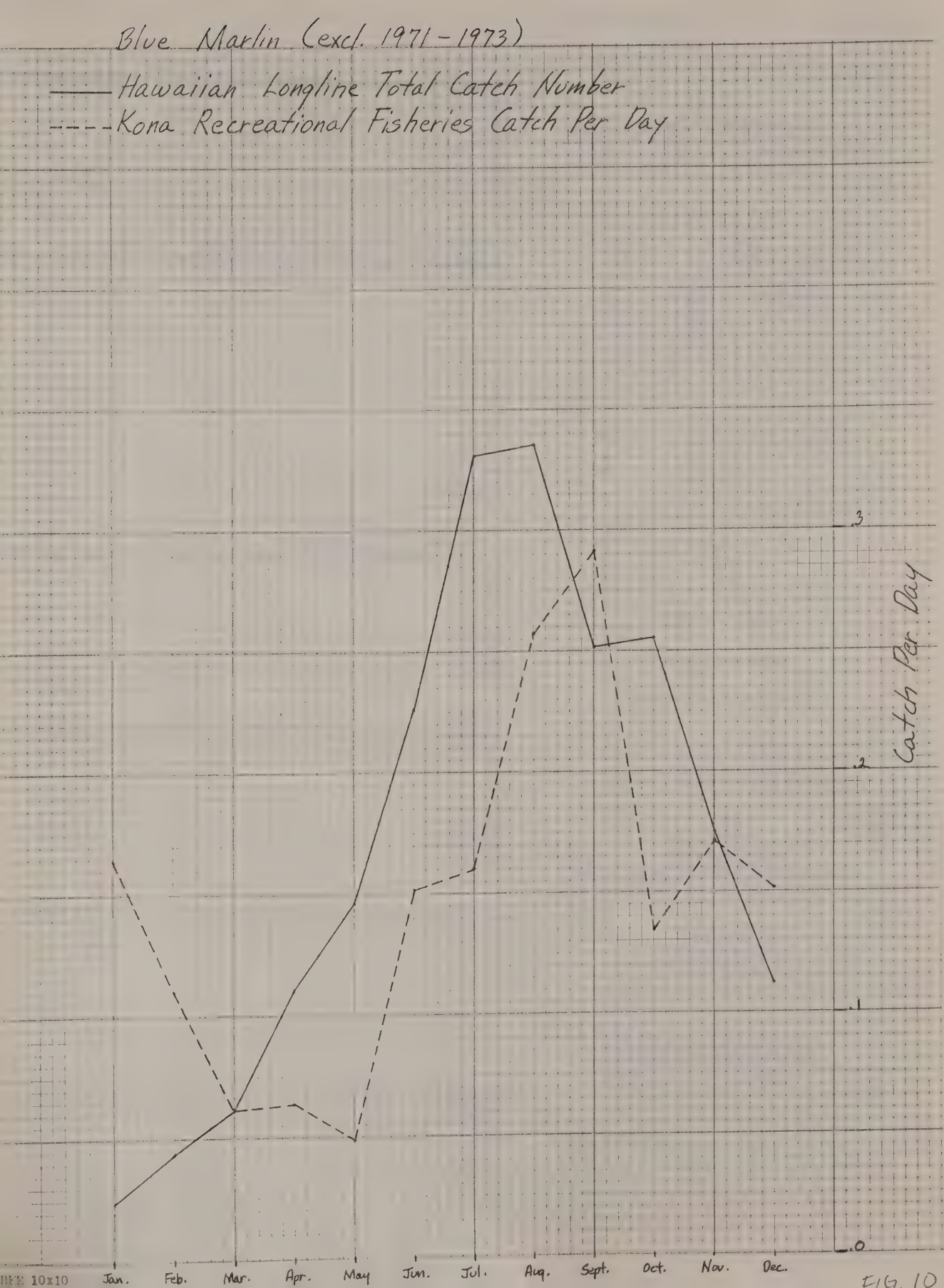

Blue Marlin (excl. 1971 - 1973)
Hawaiian Longline Total Catch Number
Kona Recreational Fisheries Catch Per Day
.3
.2
.1
.0
Catch Per Day
Jan.
Feb.
Mar.
Apr.
May
Jun.
Jul.
Aug.
Sept.
Oct.
Nov.
Dec.

FIG. 10

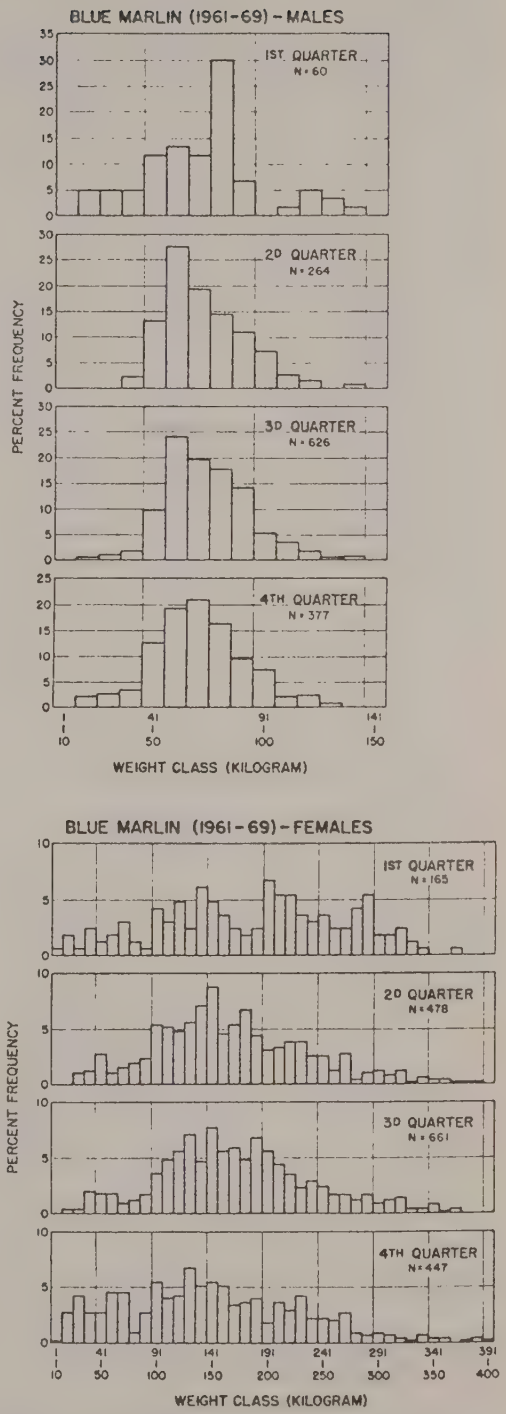
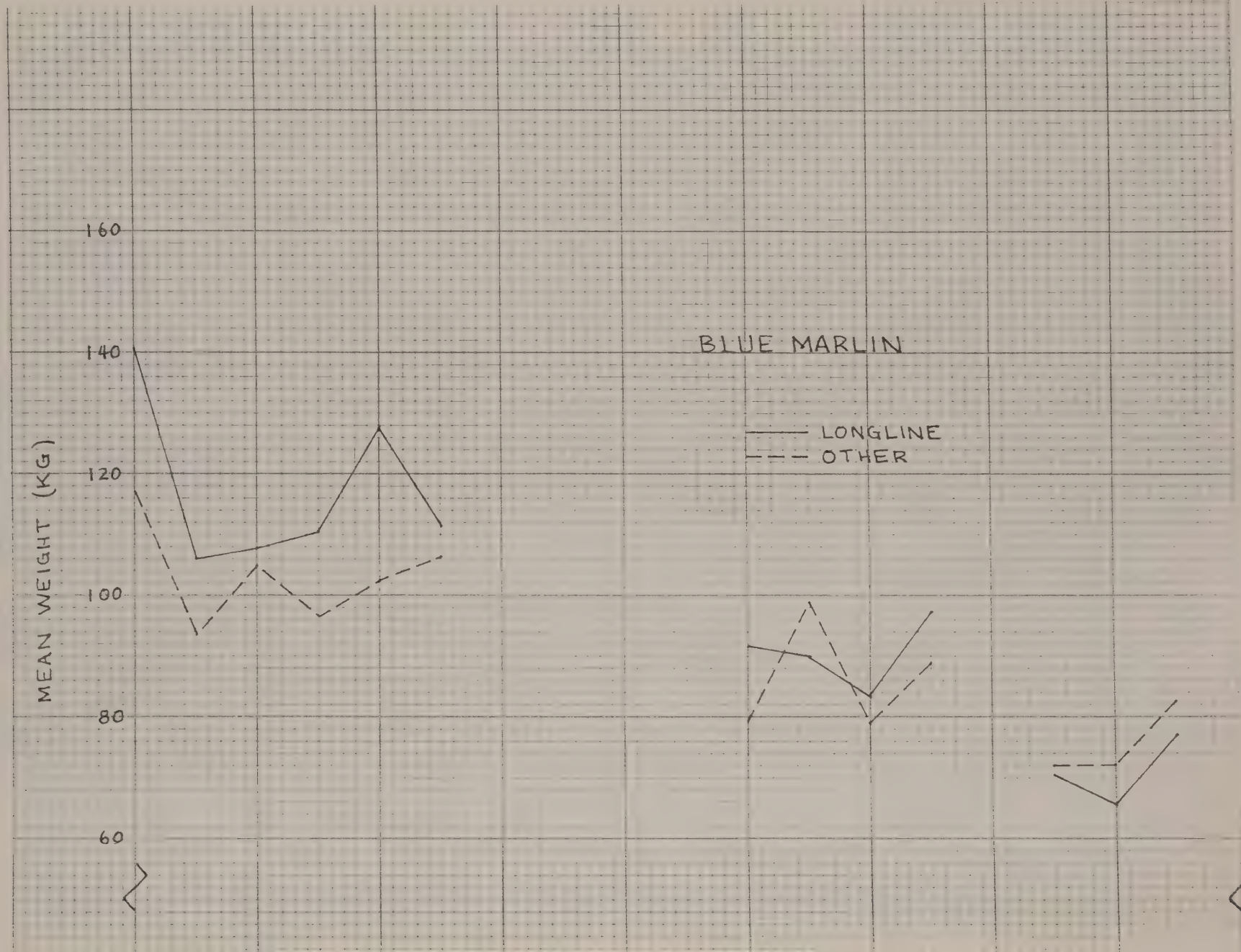
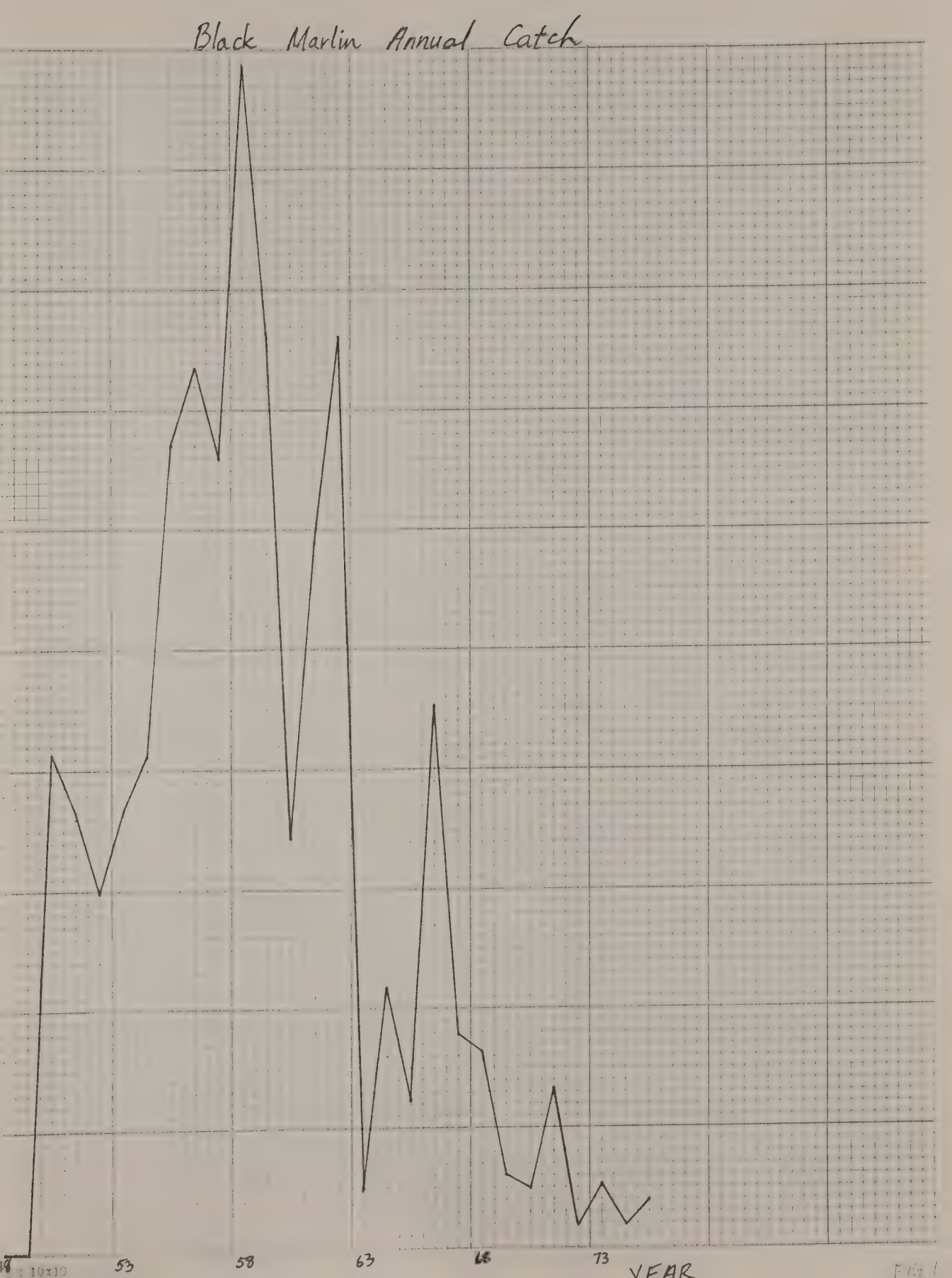


Figure 7.—Weight-frequency distribution of blue marlin.

FIG. 12


BLUE MARLIN
LONGLINE
OTHER
MEAN WEIGHT (KG)
160
140
120
100
80
60


Black Marlin Annual Catch
53
58
63
68
73
YEAR

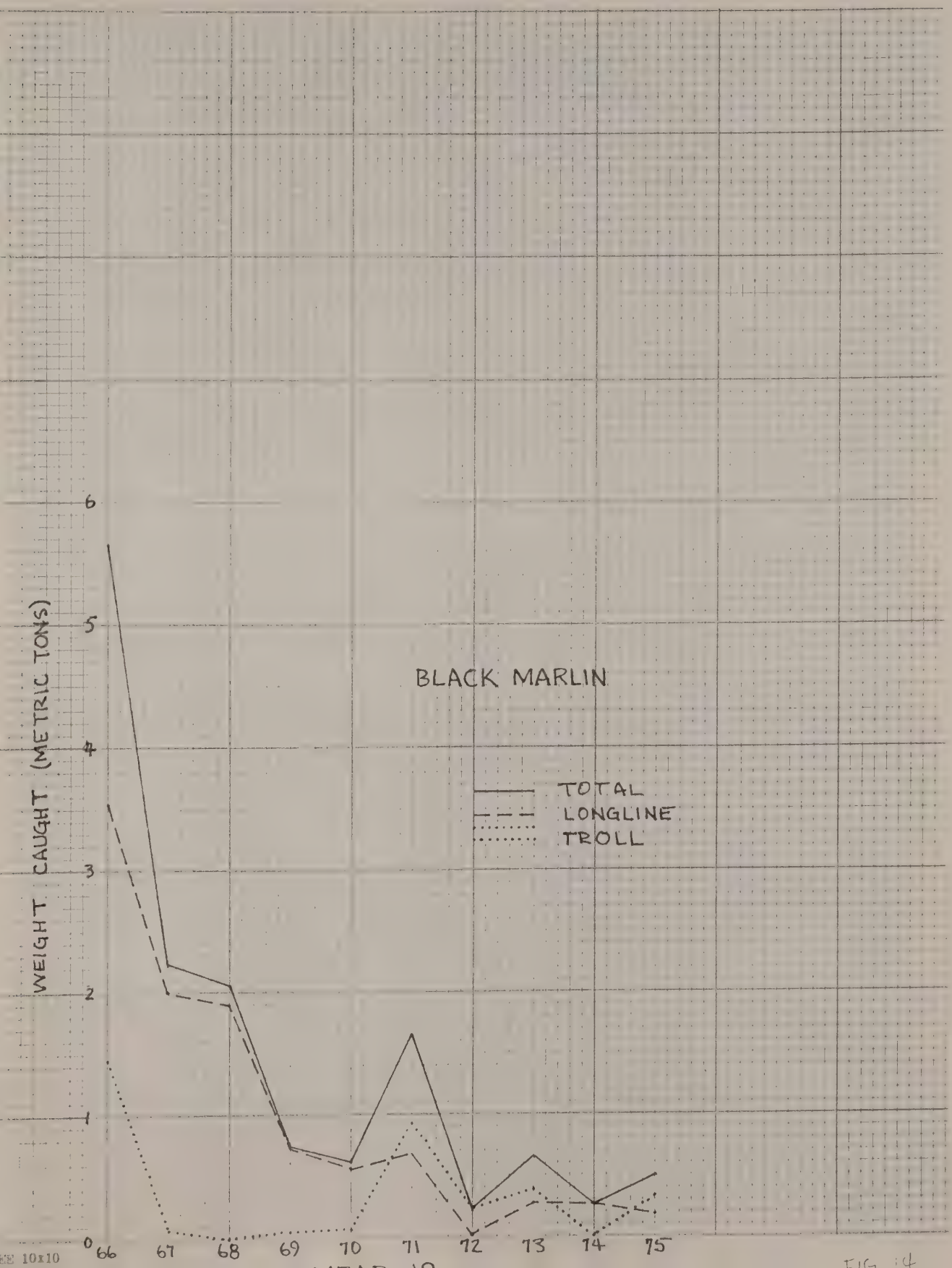
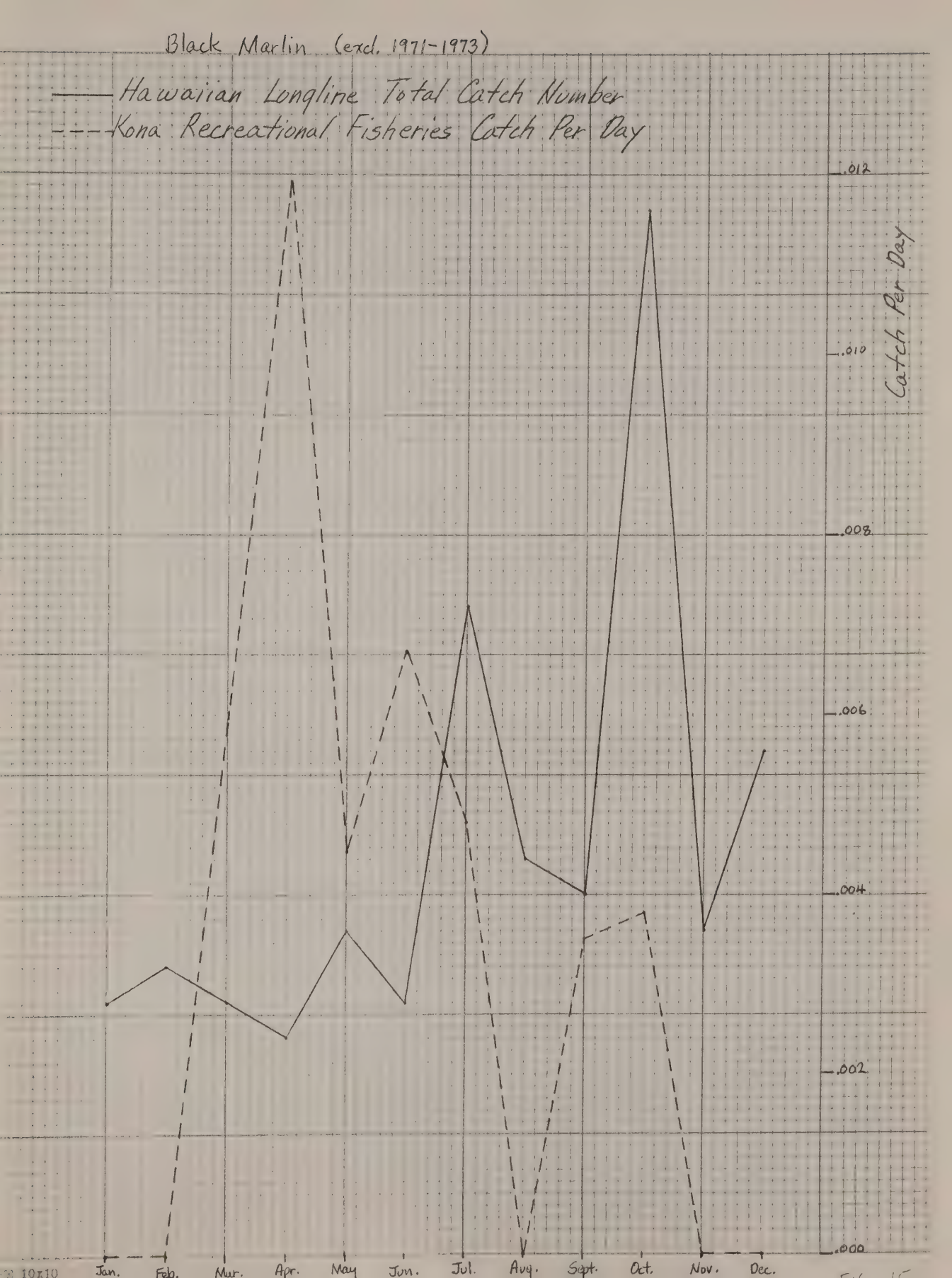
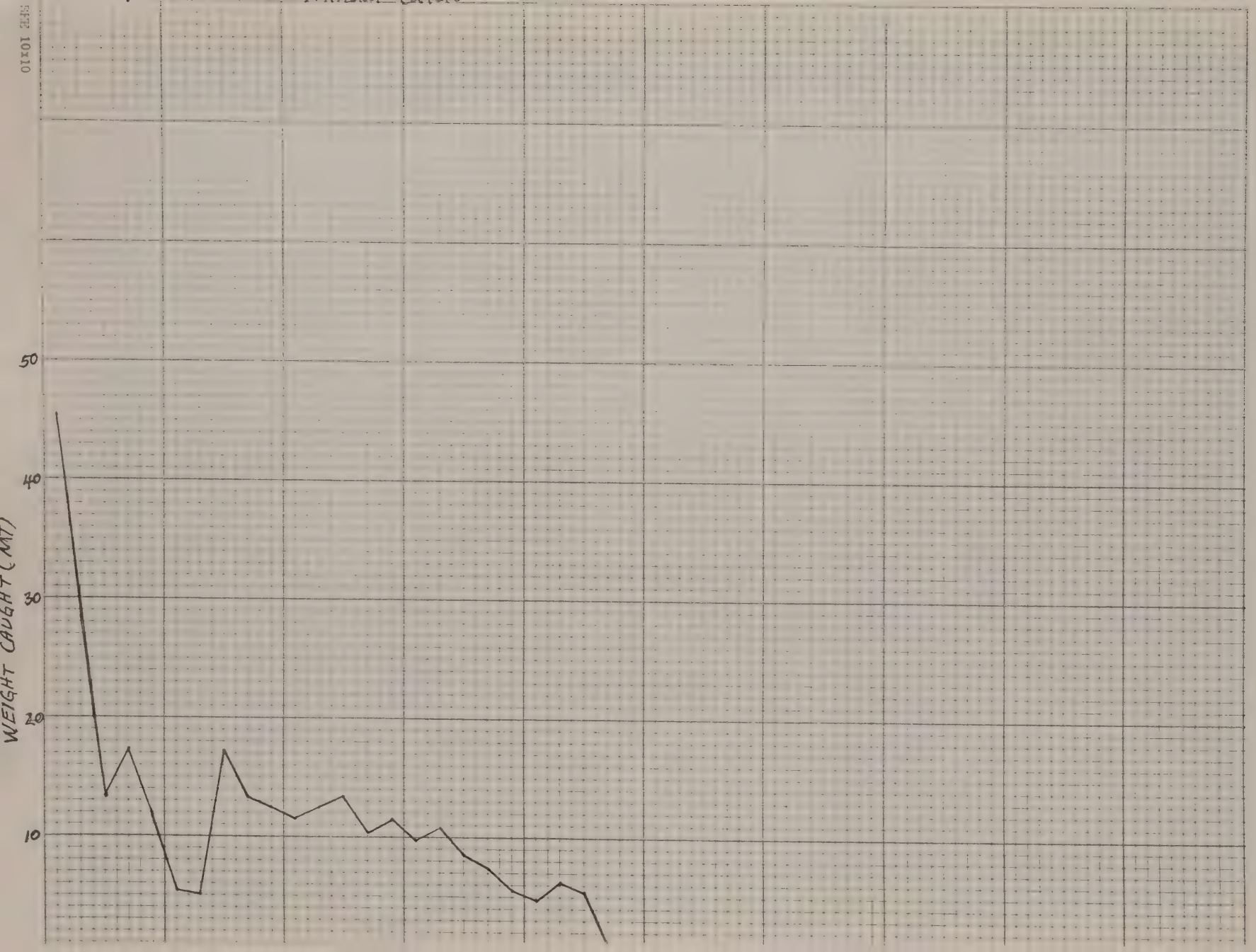
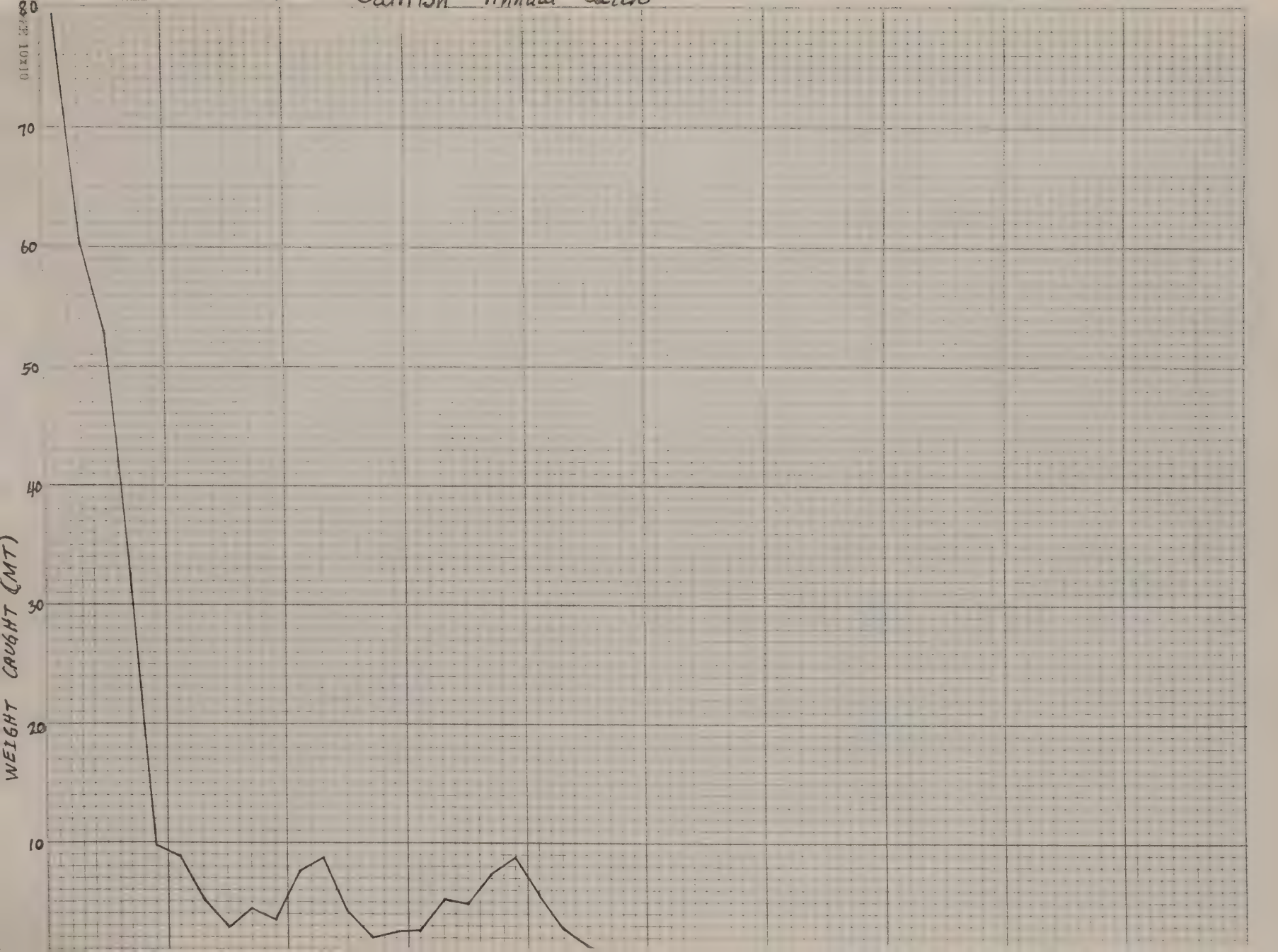

BLACK MARLIN
TOTAL
LONGLINE
TROLL
WEIGHT CAUGHT (METRIC TONS)
0
1
2
3
4
5
6
66
67
68
69
70
71
72
73
74
75

FIG. 14


Black Marlin (excl. 1971-1973)
Hawaiian Longline Total Catch Number
Kona Recreational Fisheries Catch Per Day
.012
.010
.008
.006
.004
.002
.000
Catch Per Day
Jan.
Feb.
Mar.
Apr.
May
Jun.
Jul.
Aug.
Sept.
Oct.
Nov.
Dec.


50
40
30
20
10
WEIGHT CAUGHT (KG)


80
70
60
50
40
30
20
10
WEIGHT CAUGHT (MT)

Sailfish (1959-1963)

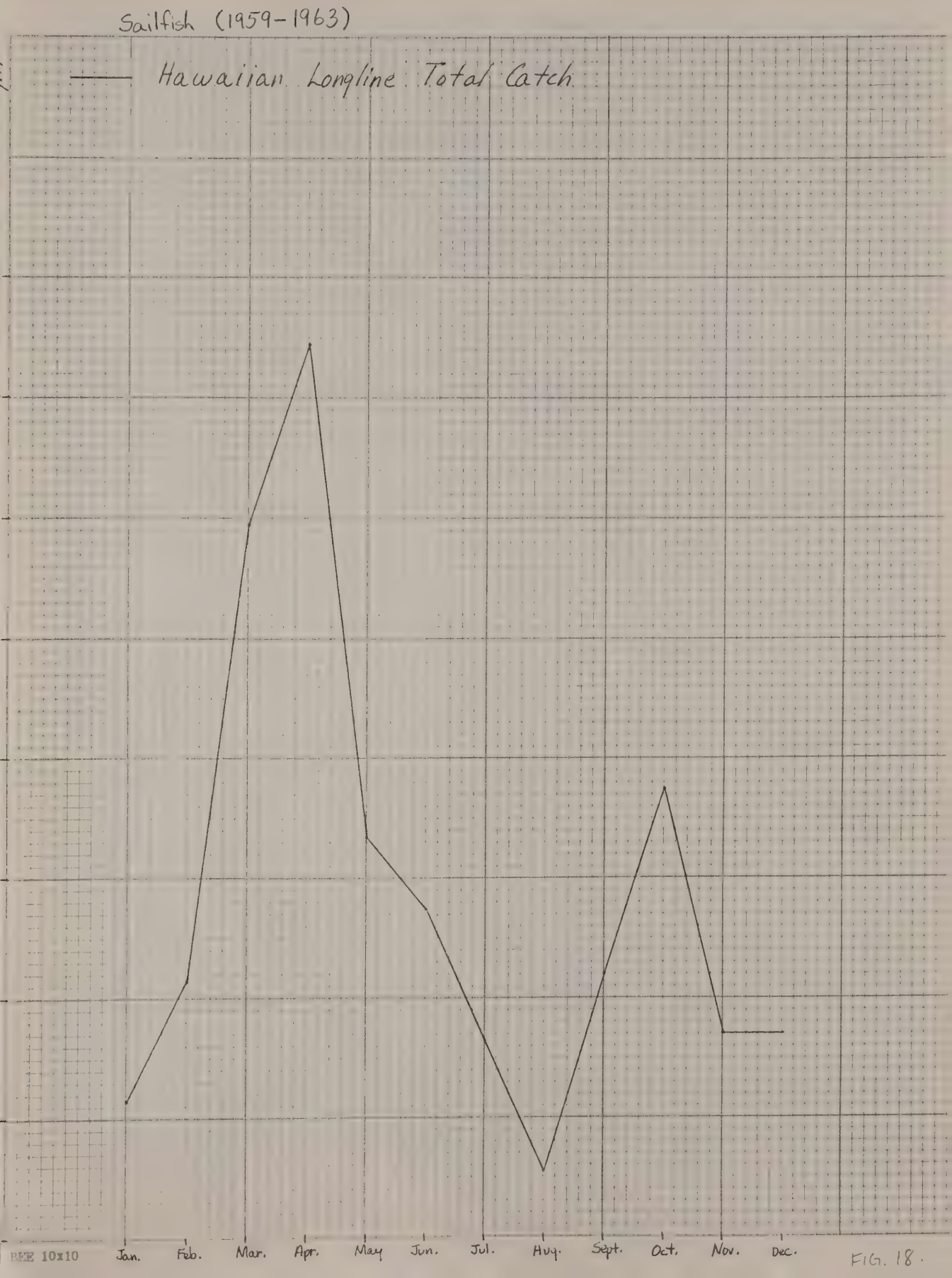
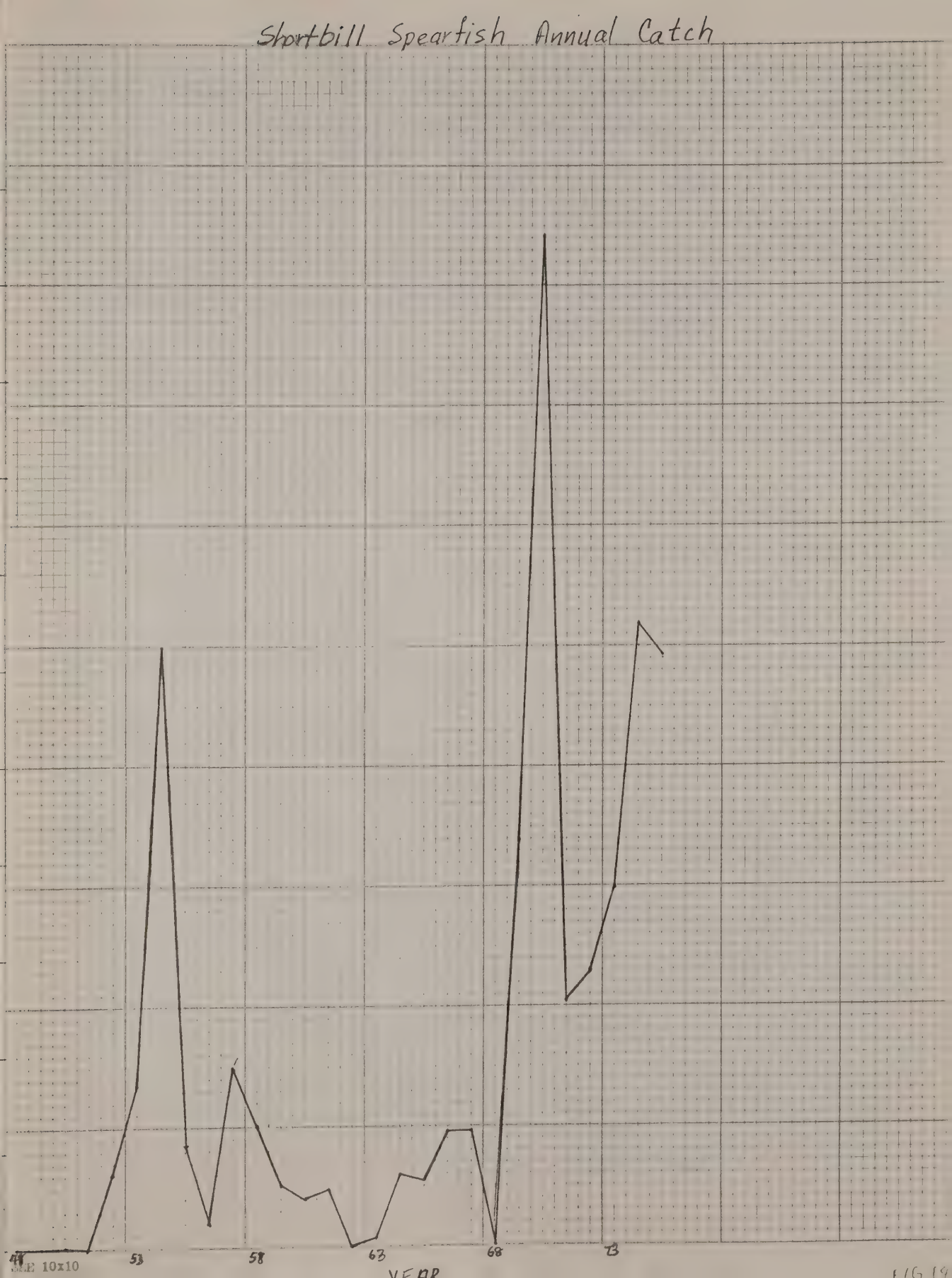
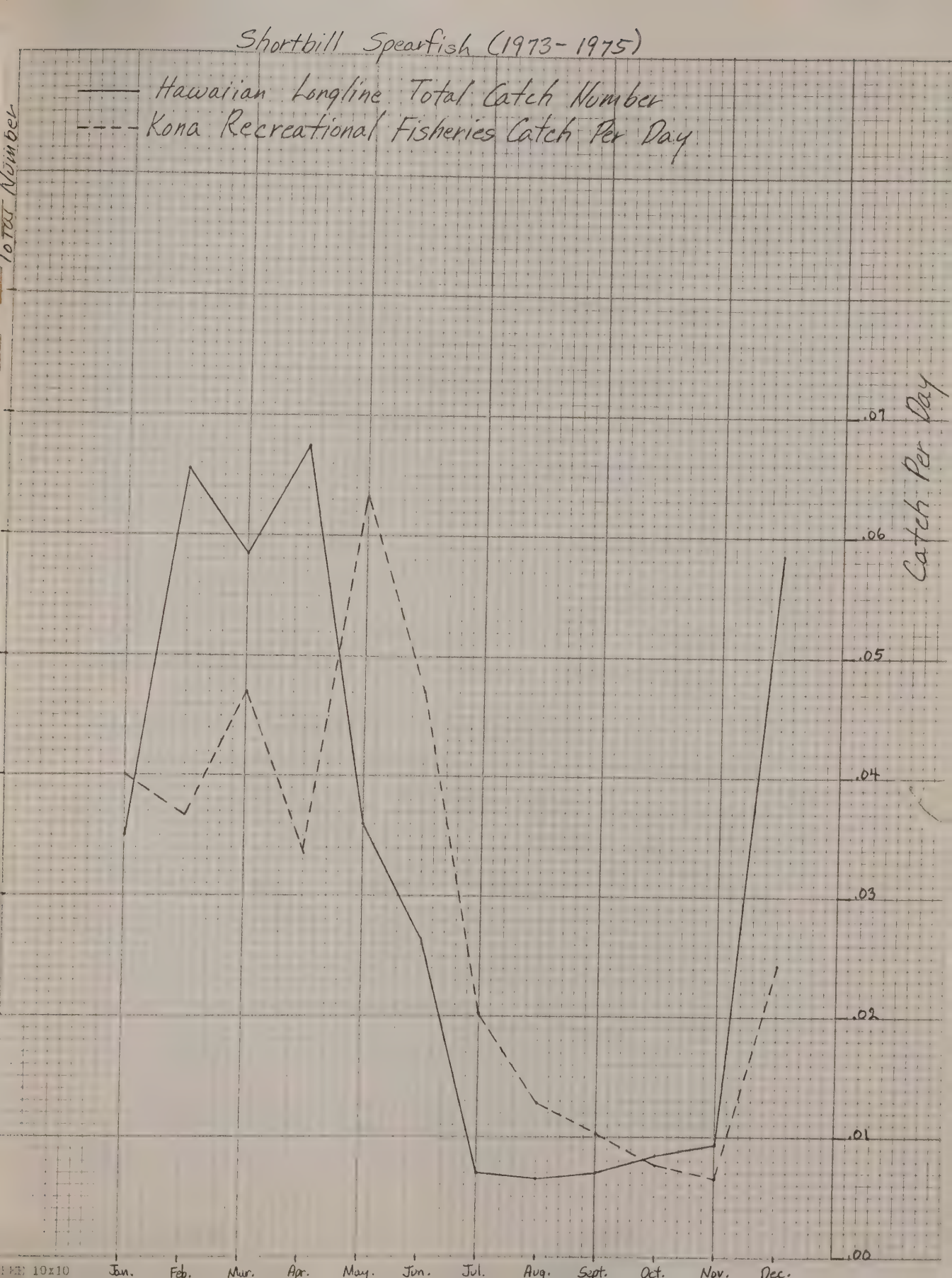


FIG. 18.


Shortbill Spearfish Annual Catch
53
58
63
68
73
YEAR


Shortbill Spearfish (1973-1975)
Hawaiian Longline Total Catch Number
Kona Recreational Fisheries Catch Per Day
Total Number
Catch Per Day
.07
.06
.05
.04
.03
.02
.01
.00
Jan.
Feb.
Mar.
Apr.
May.
Jun.
Jul.
Aug.
Sept.
Oct.
Nov.
Dec.

MARINE MAMMAL - FISHERY INTERACTIONS IN HAWAII

By

Heeny S. H. Yuen[1]

Marine mammals are involved, in one way or another, in seven fisheries in Hawaii. In one of the fisheries, the longline fishery, there are two unrelated types of marine mammal interference. From a fisherman's viewpoint, one involvement is beneficial while the others are detrimental. This paper is an account of the fisheries and the role of marine mammals in those fisheries.

The information presented was obtained from interviews with individuals in the fishing industry and field observations by Robert T. B. Iversen, John J. Naughton, and myself of the National Marine Fisheries Service, and Edward Shallenberger of Sea Life Park.

Troll Fishery for Yellowfin Tuna, *Thunnus albacares*

Trolling for yellowfin tuna with rod and reel occurs throughout the State of Hawaii, mostly in the leeward areas of the major islands. This is the fishery in which the presence of a marine mammal is beneficial to the fishermen. About 5 yr ago fishermen in the Kona area on the leeward (west) side of the island of Hawaii discovered that trolling in the vicinity of herds of spotted porpoise, *Stenella attenuata*, was effective for yellowfin tuna. Fishermen from other islands have probably adopted this practice since.

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[1]Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, Hawaii 96812. December 1977.

of taking a fish, a dolphin usually pulls out 10-15 m of line. When the topmost hooks are already on board and a dolphin strikes, the fisherman is in danger of injury from the rapidly outgoing hooks.

The Kona area is apparently the only area where bottom fishermen have a dolphin problem. The impact of these animals was serious enough to cause most of the fishermen to quit this mode of fishing. The number of *Tursiops* involved was reported to be less than 30. When questioned in December 1977, however, several fishermen indicated that only one or two dolphins appear on the fishing grounds and currently the problem is not as acute as in 1975.

Handline Fishery for Mackerel Scad, *Decapterus pinnulatus*

The catching of mackerel scad with handlines takes place at night in leeward areas over a bottom depth of 100-120 m. An incandescent bulb of about 20 w is placed underwater or directed upon the surface from the deck of the boat. For this small species of 100-300 g a light line is used. Usually six feathered jigs are attached to one line and fished at a depth of 15-25 m at the perimeter of the light.

Fishermen fishing off the Kona coast and off the Waianae coast of Oahu have complained that porpoises hovering in the dark blow once loudly, move in, and take their catch a few meters from their boats. They think that the species is the bottlenose dolphin but are not certain. Spinner dolphin, *Stenella longirostris*, and pygmy killer whale, *Feresa attenuata*, have been observed in the vicinity of these

fishermen. On the average the fishermen are bothered by porpoises one night out of four usually before 9 p.m. and after 4 a.m.

The fishermen reported that attempts to evade the porpoises by turning off the light and moving at top speed to another site several kilometers away have not been successful. The porpoises simply follow them. If they turn off the light and drift, however, the porpoises will sometimes move to another skiff in the vicinity.

Troll Fishery for Marlins

For many recreational fishermen the acme of their pastime is trolling for marlin. The major species caught by trolling is the blue marlin, *Makaira nigricans*. Black marlin, *M. indica*, and striped marlin, *Tetrapturus audax*, are also caught but uncommonly. Usually six lines of various lengths (6-40 m) are trolled simultaneously, one from each corner of the stern and four from outriggers on both sides of the boat.

Artificial lures are used most of the time. Some fishermen, particularly charter boat skippers in Kona, troll live bait which is usually skipjack tuna, *Katsuwonus pelamis* or kawakawa, *Euthynnus affinis*, weighing about 2 kg. The bait is towed at a speed of 0.5-1 m per sec (1-2 knots) compared to the trolling speed of 4-5 m per sec (8-10 knots) for artificial lures. In the Kona area the bottlenose dolphin interferes by taking the bait either while it is being caught or while it is being towed (Figure 1). Fishermen have tried to save their baits from porpoise predation by winding wire around the bait or by attaching welding rods or hooks to no avail. The porpoise just take a little longer than usual to detach the bait.

Day Handline Fishery for Yellowfin Tuna

The day handline fishery for yellowfin tuna takes place off the southeastern and western shores of the island of Hawaii. Only one hook is attached to a line. The hook is usually baited with mackerel scad and placed approximately 140 m below the surface. Some of these fishermen have reported porpoises eating the smaller (less than 15 kg) yellowfin tuna on their hooks and damaging yellowfin tuna of 40-50 kg by bumping them on the ventral side. The species involved has not been identified. One fisherman reported that in the South Point area the species is not bottlenose dolphin. He also reported that only one or two individuals out of a herd of 15-20 engage in the practice of bumping the hooked fish. There are times when this porpoise will not attack the catch at all even though they may be within 10 m away. Fishermen have tried various devices, such as an "umbrella" of welding rods that collapsed over the tuna after it was caught, but without success.

Night Handline Fishery for Tunas

The night handline fishery for tunas catches bigeye tuna, *Thunnus obesus*, yellowfin tuna, and albacore, *T. alalunga*, at the edge of the island shelf 2-20 km from shore. This fishery has recently grown rapidly. It is limited to the southern half of the island of Hawaii. The boats use 20-30 w bulbs underwater, or over surface, or both, to attract the squid, *Notodarus hawaiiensis*, which is caught for bait. The baited hooks are placed consistently at a depth of

30 m with little variation. In this fishery the fishermen have not reported any predation by marine mammals but have stated that the tunas stop biting when porpoises are around.

Longline Fishery

The longline is made up by connecting unit sections of line. Each unit consists of 380 m of mainline and five or six branch lines with hooks. The gear is floated by buoys at the end of each unit. Each unit thus describes a catenary and the entire line is a series of connecting catenaries. Older boats in the Hawaiian fleet fish 120-180 hooks on 8-12 km of line. Three newer boats fish 600 hooks on 38 km of line. This gear catches large predator species such as tunas, marlins, and sharks. Desired fishing depth can be attained by adjusting the spacing between buoys and the length of the lines connecting the mainline to the buoys. The line is usually set just before dawn and hauled before sunset.

This fishery is faced with two problems related to marine mammals. In the Kona area where fresh mackerel scad is used for bait, porpoises remove the bait from the lines. Longline fishermen in that area claim that porpoises follow their boats out and remove every piece of bait as the line is being set. As a result fishermen have done hardly any longline fishing in this area in the last 2 yr. The fishermen call the porpoise "steno" implying that it is the rough tooth dolphin, *Steno bredanensis*. This identification has not been verified.

The longline fishermen who fish open ocean areas encounter a different problem. They occasionally bring in their lines with only tuna heads on the hooks. They claim that this happens in especially

productive tuna areas and as many as 30 large tunas (50-100 kg) have been lost on a single day's set. According to them the false killer whale, *Pseudorca crassidens*, is the culprit.

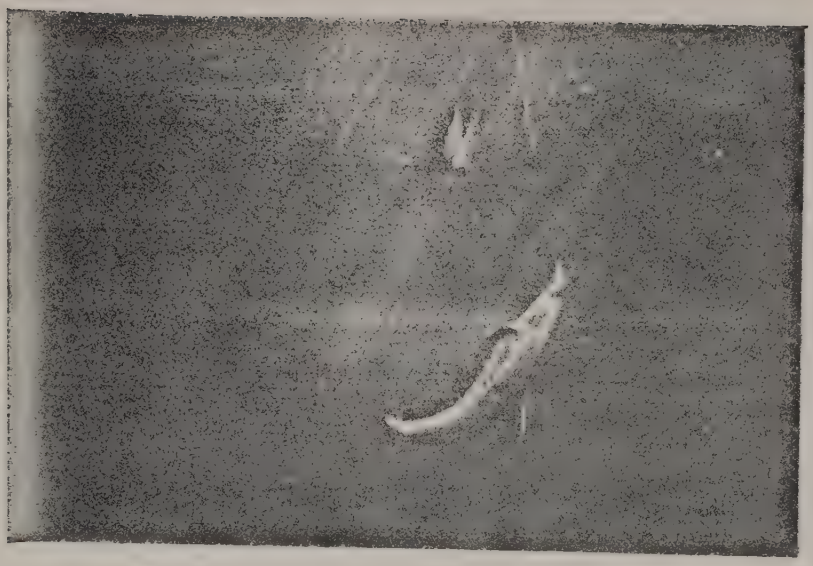
Discussion

Marine mammal behavior adverse to fisheries appears to be most serious on the island of Hawaii, particularly in the Kona area. First reports of a problem with porpoises came from that area about 5 yr ago. In 1974 porpoise interference was reported from fishing areas off South Point and Pohoiki which are on the south and southeast sides of Hawaii. Complaints about porpoises in the Waianae area of Oahu came in 1976.

According to old time fishermen of Kona only one bottlenose dolphin took their fish 25 yr ago. In the ensuing years up until 1969 a few more adopted that practice. In 1969 there was a sudden increase in the population taking fish. At that time the problem was still localized to the central area. Since then the problem has spread along the coast of Hawaii.

The extent of marine mammal predations on the baits and catches of fishermen is still not clearly defined.

Figure 1



Pacific bottlenose dolphin, *Tursiops gilli*, taking skipjack tuna from trolling gear.

Head of skipjack tuna after attack by Pacific bottlenose dolphin.

H-21-1977

Computer Simulation